NUTRIENTS IN TRIBUTARY INFLOWS TO THE PEEL-HARVEY ESTUARINE SYSTEM, WESTERN AUSTRALIA

STATUS AND TREND

by

B.N. Jakowyna

Water and Rivers Commission
Aquatic Science Branch

WATER AND RIVERS COMMISSION
WATER RESOURCE TECHNICAL SERIES
REPORT NO WRT 23
2000

Acknowledgements

The author would like to acknowledge the sincere and continuing efforts of the staff at the Mandurah section of the South-West Branch of the Water and Rivers Commission for data collection and regional advice. Many thanks must also go to the River and Estuary Investigations Branch of the Water and Rivers Commission for data management and advice. Thanks also to Malcolm Robb, Dr Jane Latchford, Rob Donohue, Dr Tom Rose, Bob Pond, Leon Brouwer, Vas Hosja and Mischa Cousins for their valuable editorial comments and feedback.

For more information contact:

Brad Jakowyna
Water and Rivers Commission
Resource Information Services Division
Hyatt Centre, 3 Plain Street
EAST PERTH WA 6004

Telephone (08) 9278 0300

Reference Details

The recommended reference for this publication is:

Water and Rivers Commission (2000). *Nutrients in tributary inflows to the Peel-Harvey estuarine system: status and trend (1983-1998): Status and Trend.* Water and Rivers Commission, Water Resource Technical Series No WRT 23.

ISBN 0-7309-7461-8
ISSN 1327-8436

Printed on 50% recycled stock
Text, Sapphire Dull 100 gsm
Cover, Sapphire Dull 250 gsm

July 2000

Contents

Figures

Tables

Summary

The Peel Harvey estuarine system has been susceptible to occurrences of nuisance macroalgae growth and phytoplankton blooms, while its tributary inflows have been susceptible to nuisance phytoplankton blooms. Both are extremely difficult to manage and control and can be attributed, in part, to the continuous export of nutrients from the catchments of the Serpentine, Murray and Harvey rivers. A water quality monitoring program was implemented in 1983 to monitor nutrients from these rivers. In 1990 the monitoring program was extended to include numerous other waterways on the Swan Coastal Plain. There are currently four monitored sites in the Serpentine region, two in the Murray region, four in the Harvey region and four estuary-feeding drains being monitored. This report provided a qualitative and quantitative analysis of total nitrogen (TN) and total phosphorus (TP) for each of the sites over their respective monitoring periods.

Classification methods were used to qualitatively assess the current nutrient water quality and to spatially compare monitored sites. Gull Road Drain has an extreme TN status; with Nambeelup Brook, Coolup Main Drain, Mealup Main Drain and Meredith Main Drain having either a high or very high TN status. Gull Road Drain, Nambeelup Brook, Mealup Main Drain and Meredith Main Drain all had an extreme TP status; with Coolup Main Drain and South Coolup Main Drain having a high and very high TP status respectively. The elevated nutrient concentrations in these tributaries indicate that the current nutrient water quality is poor and requires urgent management attention. Other monitored sites showed either moderate levels of nutrient enrichment or no enrichment, especially those tributaries that drain the Darling Scarp.

Quantitative analysis of trends in nutrient water quality can provide accurate and reliable information about how much a tributary's nutrient water quality is changing over time. Trends are a valuable tool for managers wanting to measure the rate of improvement in water quality following the implementation of catchment management initiatives or to measure the rate of degradation for impacted waterways. Of particular interest for environmental managers was the absence of decreasing trends and the prevalence of increasing trends for tributary inflows to the Peel-Harvey estuarine system. Increasing trends in TN were found in Nambeelup Brook, South Dandalup River and Meredith Main Drain. Increasing trends in TP were found in Nambeelup Brook and Caris Drain. Several monitored sites were found to show evidence of emerging trends in nutrient concentration; however, more sampling is required to statistically confirm them as trends. Increasing emerging trends were found in South Dandalup River (TP), Coolup Main Drain (TP), South Coolup Main Drain (TN and TP) and Samson Brook North (TN and TP). There were no trends in nutrient data series for the major inflows (Serpentine, Murray and Harvey rivers) discharging to the Peel-Harvey estuarine system.

At the time of this analysis it was not possible, nor intended, to relate any of the trends in the nutrient data series to specific changes in land use, agricultural/industrial practices or management initiatives. Assessments on a sub-catchment scale are necessary to determine the impact of land use decisions or whether recent management action has been effective. Further investigation may also be required to determine whether some trends in tributary nutrient water quality are reflecting long-term climatic cycles (e.g. El-Niño effects).

1. Introduction

Trends in data series are an accepted measure of degradation or improvement in surface water-quality. Temporal increases in nutrient concentration, for example, have been linked to cultural eutrophication of receiving waters (Heathwaite and Johnes, 1996; Robson and Neal, 1996; Lettenmaier *et al.*, 1991), and decreases in concentration to the effectiveness of management intervention (Stoddard *et al.*, 1996; Sanders *et al.*, 1987). Agencies with environmental responsibilities are particularly interested in trends in water quality, especially those that can be linked to changes in land-use or management initiatives.

This report describes the results of an analysis for statistical significance of trends in total nitrogen (TN) and total phosphorus (TP). The aim of the report was to describe the temporal variation in the nutrient series derived from the monitoring of tributary inflows to the Peel-Harvey estuaries. A secondary aim was to describe the trends that were statistically significant and identify those that were practically significant to environmental managers of the Peel-Harvey catchments. The current nutrient status for each monitored tributary was also reported to provide an indication of current in-stream nutrient concentrations.

1.1 Historical Background

The Peel-Harvey estuarine system is one of the most intensely studied and managed estuarine systems in Australia (WRC, 1998). Investigations into the estuarine algal problems commenced in 1975 when focused research into the estuarine ecosystem commenced. The aim of this early work was to identify the causes of excessive growth of macroalgae and to develop possible management options. The research (1975-1981) indicated that eutrophication of the estuaries was caused by an excess of nutrients, primarily phosphorus, from superphosphate fertilisers applied to soils on the coastal plain. Further studies from 1981 to 1983 confirmed the role of nutrients in drainage from the Swan Coastal Plain. It was concluded that the combination of high nutrient export from the catchment, poor exchange with the ocean and long residence times have made the estuaries susceptible to eutrophication (Deeley *et al.*, 1999; McComb and Lukatelich, 1986; Rast and Thorton, 1996).

The Western Australian state government, in recognising the widespread implications of eutrophication, charged a number of government agencies and shires to prepare and implement an Environmental Review and Management Program (ERMP). In 1985, Stage 1 of the ERMP recommended a combination of management policies that would restore the health of the estuary. This included both control and preventative measures and engineering solutions, such as the construction of the Dawesville Channel to improve mixing with the ocean. Following the review period, the EPA recommended that further investigations be conducted and that a Stage 2 ERMP be prepared when the results of these investigations became available. The Stage 2 ERMP (Kinhill Engineers, 1988) addressed in detail the environmental implications of the catchment management policies outlined in the Stage 1 ERMP.

To assess the progress of catchment management, the Stage 2 ERMP recommended interim phosphorus loading targets that were subsequently gazetted in 1988. The targets, which were based on estimates of the 60 and 90 percentile loads, are: *Annual phosphorus loads to the estuary system shall not exceed 85 tonnes in more than 4 years of 10 (on average); nor 165 tonnes in more than 1 year in 10.* In 1992, a subsequent Environmental Protection Policy (Peel Inlet-Harvey Estuary) established additional mass loading targets for the main tributary inflows to the estuaries; namely the Serpentine, Murray and Harvey rivers. In 1990, a water quality monitoring program was commissioned in the catchment of the Peel and Harvey estuaries with the aim of testing compliance with the phosphorus loading targets.

As a result, extended nutrient concentration data series are now available for 16 tributary inflows of the Peel-Harvey estuaries. The major tributary inflows have been monitored since 1983, while monitoring of the minor rivers and agricultural drains on the coastal plain commenced in 1990. Inappropriate sampling regimes and varying spatial coverage of the monitoring network meant that it was not possible to accurately test compliance with mass loading targets. However, the data series may legitimately be examined for trends in nutrient concentration that may have occurred during the last two decades of catchment management.

1.2 Regional setting

1.2.1 Geography

The Peel Harvey estuarine system is located approximately 75 km south of Perth, the capital city of Western Australia. It is a broad, shallow coastal lagoon situated on the western edge of the Swan Coastal Plain with a total area of approximately 130 km^2. The Harvey Estuary is 61 km^2 in area and the Peel Inlet is somewhat larger at 75 km^2. Both basins are of similar volumes with the Harvey Estuary at 56 million cubic metres and the Peel Inlet at 61 million cubic metres (WRC, 1998).

The estuaries flow into the Indian Ocean via the Mandurah Channel and (since 1994) the Dawesville Channel. The catchments of the estuaries are drained by three major river systems, the Serpentine, Murray and Harvey rivers; with some minor drains discharging directly to the estuaries. The cumulative area of the catchment is approximately 11 930 km^2.

The Peel-Harvey catchment can be divided into three broad regions: the coastal plain, forest region, and the agricultural region. The Swan Coastal Plain is bound to the east by the Darling Scarp and to the west by the ocean and has been largely cleared of remnant vegetation. The forested region flanks the western part of the Darling Range and the agricultural region is situated to its east.

1.2.2 Climate

The Peel-Harvey region has a Mediterranean climate with hot dry summers and cool wet winters. About 90 percent of the annual rainfall occur between April to October. Average annual rainfall ranges from 700–800 mm along the coastal zone to close to 1000 mm in the areas adjacent to the scarp. Approximately 50% of the total annual volume of water enters the estuary between July and August, with more than 66% entering between June to October. Most streams experience little or no flow between December through to April, comprising mostly of groundwater input (Kinhill Engineers, 1988).

1.2.3 Geology

The major soil types of the Peel-Harvey region are displayed in Figure 1. Four major soil types are present in the Peel Harvey catchment, each with different structure and capacity to bind and retain nutrients. Deep grey sands are found to the east of the Serpentine River and to the west of Harvey River. The sands are porous, have a low organic content and a poor nutrient retention capacity. The duplex soils are common in most coastal plain catchments and at the base of the Darling Scarp. They are naturally infertile and possess a low phosphorus binding and retention capacity with an impermeable clay layer at 0.2–1.0 metre. A narrow band of red earths can be found along the eastern fringes of the coastal plain, which are porous but possess a good phosphorus binding capacity due to a high iron content. The loams and clays are comparatively more fertile, have a good ability to bind nutrients and little leaching potential. This soil type is found on the floodplains of the Serpentine and Harvey rivers and in the Waroona district (Ruprecht and George, 1993; Kinhill Engineers, 1988).

1.2.4 Hydrology

The Murray and Harvey drainage basins are two of six major drainage divisions on the Swan Coastal Plain. The headwaters of each basin are either located on the Darling or Dandalup Plateaus. Runoff from the plateau and areas adjacent to the rivers on the coastal plain, plus groundwater discharge contribute water to the Serpentine, Murray and Harvey rivers. Large storage dams have been built on the Serpentine River, tributaries of the Murray River and on the Harvey River which has significantly altered their natural flow regimes. Groundwater pervades the superficial formations beneath the coastal plain, so runoff from the coastal areas is probably a minor component of total discharge to the estuaries. However, there may be a general reduction in rainfall infiltration at the base of the scarp as the clay content of the soil increases (Davidson, 1995). In the cleared rural catchments stormwater is directed to a network of drains and, combined with water imported for irrigation, has increased net recharge to the underlying aquifers (Gerritse *et al.*, 1990). This has caused a rise in the local watertable and increased the baseflow component for most surface drainage for urban areas and areas extensively cleared for agriculture.

1.2.5 Land use

Land use types in the catchments of each monitored waterway are listed in Table 1.

Land use in the Peel-Harvey region is highly diversified. Residential, commercial and agriculture practices flank the estuaries, while agriculture is the dominant land use on the coastal plain region. Stock grazing and pasture development are the most common agricultural activities, although horticulture and industry are also present. A small

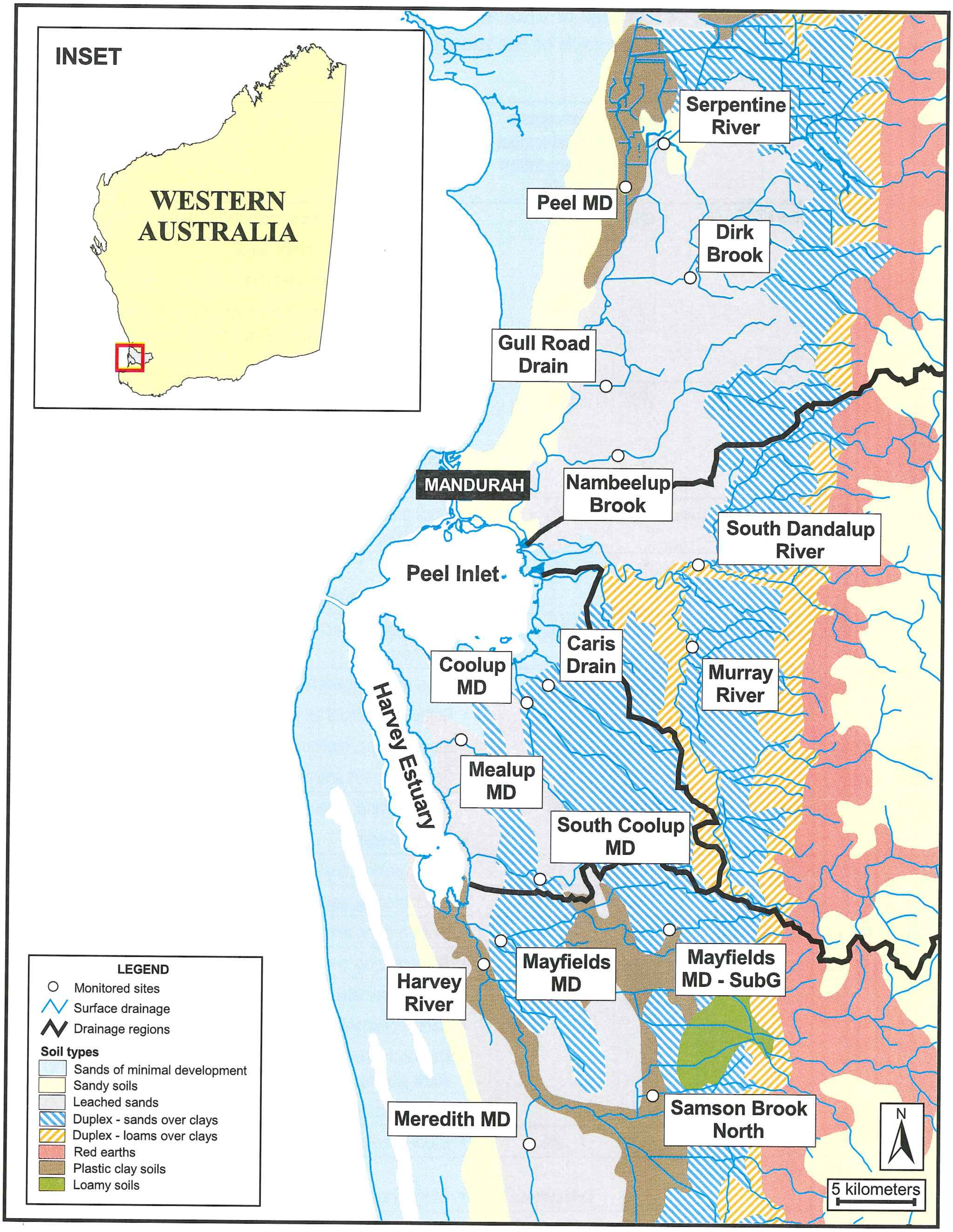

Figure 1: Location of monitoring sites in the catchment of the Peel Harvey Estuaries. The catchment boundaries of the four major regions are also shown—the Serpentine region (Top), Murray region (Centre Right), small drains to the estuary(Centre) and the Harvey region (Bottom).

Table 1: Catchment area, percentage of total annual discharge to the Peel-Harvey estuaries and main catchment land uses for each of the monitored sites. The regions correspond to the boundaries shown in Figure 1.

Region	Catchment	Area (km^2)	Approximate % total annual surface inflow to PHES	Land use
Serpentine	Serpentine River	1 128	12%	• Several large townships, including Mandurah • Commercial and industrial areas • Undergoing rapid urbanisation • Stock grazing, pasture production, horticulture, stock holding yards, piggeries, poultry farms, dairies, floriculture • Forested areas
	Peel Main Drain	121	1%	• Undergoing rapid urbanisation • Some industry and commercial centres • Stock grazing, pasture development, piggeries, poultry farms, horticulture, stock holding yards
	Dirk Brook/Punrack Drain	138	1%	• Stock grazing, pasture development, turf farming, piggeries, horticulture
	Gull Road Drain	7	< 1%	• Piggery • Pasture development and grazing
	Nambeelup Brook	115	1%	• Stock grazing, pasture development, dairies, horticulture, plantation
Murray	Murray River	7 180	60%	• Several large townships, including Pinjarra • Some commercial areas and industry (refinery) • Stock grazing, horticulture, pasture development, dairies • Forested areas and plantations
	South Dandalup River	670	3%	• Stock grazing, pasture development, dairies, horticulture • Forested areas
Small Drains to Estuaries	Caris Drain	23	< 1%	• Stock grazing, pasture development, dairies
	Coolup Main Drain	52	< 1%	• Stock grazing, pasture development, piggeries
	Mealup Main Drain	25	< 1%	• Stock grazing and pasture development
	South Coolup Main Drain	32	< 1%	• Stock grazing, pasture development, turf farming, dairies
Harvey	Harvey River	1 185	20%	• Several townships • Some commercial areas and industry (mining) • Dairies, horticulture, turf farming, pasture development, stock grazing • Forested areas and plantations
	Mayfields Main Drain	112	2%	• Stock grazing, pasture development, turf farming, dairies
	Mayfields Main Drain—SubG	10	to Mayfields M.D.	• Stock grazing, pasture development, dairy
	Samson Brook North	19	to Harvey River	• Stock grazing, horticulture, dairy and pasture development • Some industry (mining)
	Meredith Main Drain	49	to Harvey River	• Stock grazing and pasture development • Plantation

portion of the region is irrigated and has a developed network of drains. Approximately 75% of the coastal plain part is cleared of native vegetation (Ruprecht and George, 1993). The land east of the Darling Scarp remains largely forested with native *Eucalyptus marginata* and several rivers in the region have been dammed. The land to the east on the plateau is largely cleared for stock grazing, pasture development and cereal crops.

1.3 Nutrients in waterways

1.3.1 The role of nutrients in waterways

Nitrogen and phosphorus are the two major essential elements to plants. High concentrations of nutrients in waterways will determine the maximum biological productivity of the system and have been linked to excessive growth of nuisance plant species.

Nutrients can stimulate the growth of plants to the extent that they begin to dominate an aquatic system, often to the exclusion of other species. Such systems are said to have become 'simplified ecosystems' and typically contain high populations of only a few species. Once simplified ecosystems occur the natural cycling of nutrients in the system may become very difficult to alter and thus problems become persistent and recurring. The most common nuisance plants in the Peel and Harvey estuarine system include the macroalgae (e.g. Rhodophyta and Chlorophyta) and phytoplankton species (e.g. cyanophytes, diatoms and dinoflagellates) (Lord *et al.*, 1998).

A range in nutrient concentrations has been reported for Australian waterways. It is recognised that TN concentrations greater than 1.0 mg/L and TP concentrations greater than 0.1 mg/L are of concern in south-west Western Australia (WRC, unpublished data). These guideline concentrations have been derived from ANZECC guidelines (1992) to suit freshwater riverine systems for south-west W.A.

1.3.2 Sources of nutrients supplied to waterways

Most nutrients present in a catchment are stored in its soils and transported to waterways via flowing water. Naturally occurring sources of nutrients are derived from weathering processes, fixation of atmospheric nitrogen by some plants and from leaching of soils. Human activities such as sewage outfalls, land clearing, fertiliser application, industrial effluent, urban runoff and the inappropriate disposal of domestic detergents and soaps can add to the store of nutrients in catchments or increase nutrient export from the catchment to waterways.

Changes in nutrient water quality of waterways can be attributed to natural variation or by a change in a nutrient source. Management agencies are generally most interested in trends caused by a change in the supply or loss of nutrients from catchments. The intensity or scale of change in the catchment will affect the magnitude of trend in nutrient concentration of a receiving waterbody (Heathwaite and Johnes, 1996). Small scales of change, usually from point sources, produce a sudden and localised change in water quality that is relatively easy to detect. Changes in large scale sources of nutrients, usually referred to as diffuse sources, are more difficult to detect and quantify in terms of a change in water quality. Any confirmed change in the supply and transport of nutrients to waterways, large or small, is of interest to environmental management agencies.

Point sources of nutrients derived from residential and commercial land use (sewerage, fertilisers and detergents) and industry (chemicals, effluent) on the Swan Coastal Plain are well known (Gerritse and Adency, 1992). Other potential sites for point source pollution include land-fill sites, contaminated sites and agricultural properties with intensive livestock practices (e.g. piggeries, poultry farms, dairies, stock holding yards). The composition of nutrient species from point sources depends on the chemical discharged and any biodegradation or treatment processes occurring prior to discharge. The discharge rate of nutrients to a waterway can vary from regular periods (controlled discharge) to inconsistent, event-based occurrences (chemical spills, overflows). Both are generally characterised by reduced travel times of pollutants through the catchment.

In contrast, diffuse sources are derived from large areas in the catchment. Diffuse sources are believed to provide a majority of nutrients delivered to the tributaries on the Swan Coastal Plain (Hodgkin and Hamilton, 1993; Ruprecht and George, 1993). Diffuse sources of nutrients largely originate from rural practices including fertilised arable lands, pasture, orchards and intensive horticulture practices, although fertilisers applied to urban gardens and parks are also appreciable (Gerritse and Adency, 1992). The transport of diffuse sources of nutrients to waterways can occur via a variety of hydrologic pathways, such as surface run-off, shallow sub-surface flow and groundwater. Both nitrogen and phosphorus are mobilised and transported through the catchment by very different mechanisms.

1.3.3 Transport mechanisms for nutrients

Nitrogen exists in several forms, most of which are soluble and rapidly transported through the catchment via surface run-off, sub-surface and groundwater flows. Oxidised forms of nitrogen (nitrates and nitrites) are common in arable soils and flowing waters, while reduced forms of nitrogen (ammonia and ammonium) are common in surface run-off, erosion and stagnant waters. Organic nitrogen, associated with biological material, is less mobile. Travel and residence times of nitrogen species in the catchment will largely depend on flow rates of surface drainage or groundwater. Mobilisation of soluble nitrogen species also depends on rates of mineralisation/assimilation processes and the rate of denitrification (N_2 gas emission) (Heathwaite and Johnes, 1996; Reddy and D'Angelo, 1994). Studies have shown that microbial denitrification can be an important removal process in saturated soils (Slater and Capone, 1987; Smith and Duff, 1988) and that as little as 20% of nitrogen added to a sandy catchment may reach the estuary (Valiela *et al.*, 1997).

Phosphorus, mostly as inorganic phosphate, is not as mobile and tends to strongly adsorb to most soils (particularly with iron and aluminium oxides) and particulate material. Particulate forms of phosphorus, such as organic material or inorganic minerals (e.g. apatite), are less mobile. The net accumulation of phosphorus in the soil results in a plume of phosphorus slowly moving through the catchment. Travel and residence time of phosphorus in the catchment therefore depends on the recharge rate to groundwater, rate of adsorption to soil particles and the extent of soil saturation (Gerritse, 1990; 1992). Mobilisation of phosphorus depends on both the physio-chemical processes occurring at the soil-water interface, sediment resuspension and erosion processes occurring at exposed soil surfaces (Reddy and D'Angelo, 1994).

As an example, the travel time of phosphate in one metre of soil in the upper Murray catchment (Darling Plateau) is estimated to be in the order of centuries. Particulate phosphorus in surface run-off from the loams and clays in the upper catchment is probably the major form, although localised "hot spots" are likely due to sandy soils and areas irrigated with sewerage effluent. Depending on land use, travel times of phosphate per metre of soil on the Darling Plateau and Scarp are estimated to range between a century to millennia. This is because the high iron and aluminium oxides content of the lateritic (red earth) soils of the Darling Scarp readily bind phosphorus thereby reducing export rates. Phosphorus is probably only exported from the plateau and escarpment soils in particulate form following storm events or erosion events. In contrast, many soils of the lower Serpentine catchment (on the Swan Coastal Plain) are sands that have a low adsorption capacity and readily leach phosphorus. Most of the phosphorus transported in the coastal sands are likely to be via sub-surface flows or groundwater and will probably have travel times that vary up to fifty years per metre (Gerritse, 1992).

1.3.4 Changes in the level of nutrients in waterways

Because of lags in transport time, linking a trend in nutrients to a change in catchment condition is difficult. Trends may be due to an interaction of a variety of factors such as land use, farming practices, geology and the many hydrological pathways from the catchment to the waterway (Heathwaite and Johnes, 1996). However, because the transport processes are so different for point and diffuse sources of nutrients, each is likely to result in a characteristic trend. Trends in nutrient water quality due to point sources are likely to be characterised by a "step change" and may be attributed to either a change in the relative number of point sources or a change in emission levels (e.g. regulatory licensing of industrial effluent). Trends in diffuse sources of nutrients in catchments are likely to be characterised by a steady change in water quality over a much longer period. There have been very few or no attempts in Western Australia to characterise the types of trends that can be expected in catchments subject to changes in land management.

Trends in data series may also be introduced by factors other than by changes in the supply and transport to waterways. Chance may introduce a trend component to a long data time series. All data series generally have some evidence of an increasing or a decreasing trend. The element of chance is accounted for by using statistical inference, which ascribes a probability of the trend in the data reflecting a trend in the monitored waterway.

Natural variation in hydrologic factors may also influence the mobilisation of nutrients and their concentration in waterways. Concentration of nutrients in waterways sometimes increases during storm events due to the influx of nutrient rich material. A change in sampling regimes (i.e. opportunistic, fixed interval, stratified, etc) over the monitoring period can also create the illusion of trend. Statistical methods cannot account for this uncertainty. The influence of variation in flow must first be modelled so hydrologic factors on the variation in the data can be accounted and adjusted for.

Other changes in water quality may result as monitoring programs mature and as management agency experience in their operations increases over time. Changes in analytical procedures or methodologies may also influence variation in data series. The introduction of a quality assurance and control (QA/QC) systems and laboratory auditing may improve sample collection, sample handling, storage and analytical chemistry. These changes in QA/QC will result in a uniform change for all monitored sites and represent a sudden shift in the distribution and spread of the collected data (Loftis, 1996). Care should therefore be taken to record all changes in the operation of the monitoring program so any trends due to changes in methodology can be appropriately interpreted.

2. Methods

2.1 Sampling and chemical analysis

Monitoring of the three major tributary inflows to the Peel-Harvey estuarine system (Serpentine, Murray and Harvey rivers) commenced in 1983. Samples were initially collected using a combination of fixed intervals and opportunistic (infrequent sampling of storm events) sampling regimes. In the late 1980s to early 1990s, the monitoring program was set to a weekly fixed interval regime and extended to include other waterways in the catchment. Peel Main Drain and Mayfields Main Drain (SubG) sites were closed in 1993.

From 1983 to 1993, samples were collected only while the ephemeral waterways were flowing in winter and spring. No sites were sampled during the summer period regardless of waterway permanency. Prior to 1993, all monitored sites were also gauged for discharge continuously; however because of funding shortfalls some gauging stations were de-commissioned. From 1994 samples were collected for the duration of flow in the waterway.

One litre grab samples were collected from each of the monitored sites (Figure 1). The samples were chilled and transported on the day of collection to a laboratory where the samples were frozen, stored and then analysed for total nitrogen (TN) (APHA 1995, method reference 4500-Norg D) and total phosphorus (TP) (APHA 1995, method reference 4500-P B/F) using persulphate digests.

2.2 Statistical analysis for trends

Nutrient data series contain several sources of variation: flow variation, seasonal variation, trend and random components (Hipel and McLeod, 1994). Changes brought about by human activity will usually be superimposed on natural sources of variation. In this report the influence of flow and seasonal variation was examined prior to analysis for trending periods in the nutrient data series. Although the primary objective is to detect trends over time, sources of natural variation must be known and adjusted for prior to analysis. This will provide management with an improved perception of change in nutrient concentration that are (more than likely) linked to human intervention or influences within the catchment.

Non-parametric significance tests were used in this report to identify statistically significant trending periods in a nutrient data series. Non-parametric tests were used because they are not affected when the distribution of data is not normal, are insensitive to outliers and are not affected by missing or censured data (Loftis *et al.*, 1991).

2.2.1 Assumptions

An assumption of the trend tests is that the trends are consistently increasing or decreasing, otherwise known as monotonic changes (Helshel and Hirsch, 1992). If concentrations vary non-monotonically over the period being analysed the results of linear tests for trend may be misleading (Robson and Neal, 1996). For this analysis, the assumption of monotonic change was verified by a visual examination of a LOWESS (Locally Weighted Scatterplot Smooth) line fitted to the data over the period of interest (Helshel and Hersh, 1992; Aulenbach *et al.*, 1996).

Another assumption of the trend tests is that samples in a data series must be independent. If the data series are not independent (that is, exhibits auto-correlation) the risk of falsely detecting a trend is increased (Esterby, 1996; Ward *et al.*, 1990). A correlated data series contains surplus data and ultimately results in the little or no net information gain. As a rule, the level of serial correlation in a data series increases as the frequency of sampling increases. The maximum sampling frequency possible without encountering serial correlation can be thought of as the point of information saturation (Ward *et al.*, 1990).

2.2.2 Testing for statistically significant changes

For this report, the Mann Kendall test was used to determine the statistical significance of the trending periods (Gilbert, 1987). It is an example non-parametric test and was only used when the data series exhibited independence (i.e. no correlation in the data series) (Figure 2, A and B).

When seasonal cycles were evident in a data series (Figure 3A) the Seasonal Kendall test was used to test for trend. The Seasonal Kendall test is a variant of the Mann Kendall test that accounts for the presence of seasonal cycles in the data series (Gilbert, 1987). Seasonal cycles in nutrient concentration are common in waterways and can be introduced by natural cycles in rainfall, runoff, tributary hydrology and seasonal variation in groundwater height. The presence of seasonal cycles in a nutrient data series can introduce correlation to the data series that will complicate the detection of trends. Therefore the detection of seasonal variation in the nutrient data series was performed using an auto-correlation analysis (Figure 3B).

A trend will be found to be statistically significant when the magnitude of the change is large relative to the variation of the data around the trend line. Unfortunately, when analysing long periods with large sample sizes any trend no matter how small will be statistically significant (Loftis, 1996; McBride *et al.*, 1993; Loftis *et al.*, 1991). The identification of a statistically significant trend should be seen as filter that removes small drifts in concentration from further consideration. Further analysis using sample size is required to determine whether a sufficient number of 'independent' samples were collected to detect a trend.

2.2.3 Removing variation due to flow

Nutrient concentrations in waterways can also be affected by changes in discharge. Flow/concentration relationships may create or mask trends in a fixed-interval data series. For this reason, trend analysis was also carried out on the data after it was adjusted for the effects of variation due to flow. The relationship between nutrient concentration and flow was modelled using a LOWESS fit on the flow/concentration response (Esterby, 1996; Robson and Neil, 1996; Lettenmaier *et al.*, 1991). The difference or 'residuals' between the observed and LOWESS modelled concentrations are known as flow-adjusted concentrations (FAC), as shown in Figure 4A (Hipel and McLeod, 1994). Subsequently, the flow-adjusted concentrations were reordered in time (Figure 4B) and then analysed for trend (Gilbert, 1987; Helshel and Hersh, 1992; Harned *et al.*, 1981; Hipel and McLeod, 1994; Lettenmaier *et al.*, 1991). The flow-adjustment process often helped to remove seasonal variation (as shown by comparing Figures 3A and 4B), although some evidence of seasonal variation often remained in the flow-adjusted data series.

2.2.4 Estimating the rate of change

The Sen slope estimator was used to estimate the slope of the trend line (Gilbert, 1987). The Sen estimate is the median slope of all slopes calculated using all inter-annual pairs of observations. In the presence of seasonal cycles the Seasonal-Kendall slope estimator was used (Gilbert, 1987), which is the median slope of all slopes calculated using pairs of observations collected at the same time of the year (Figure 5).

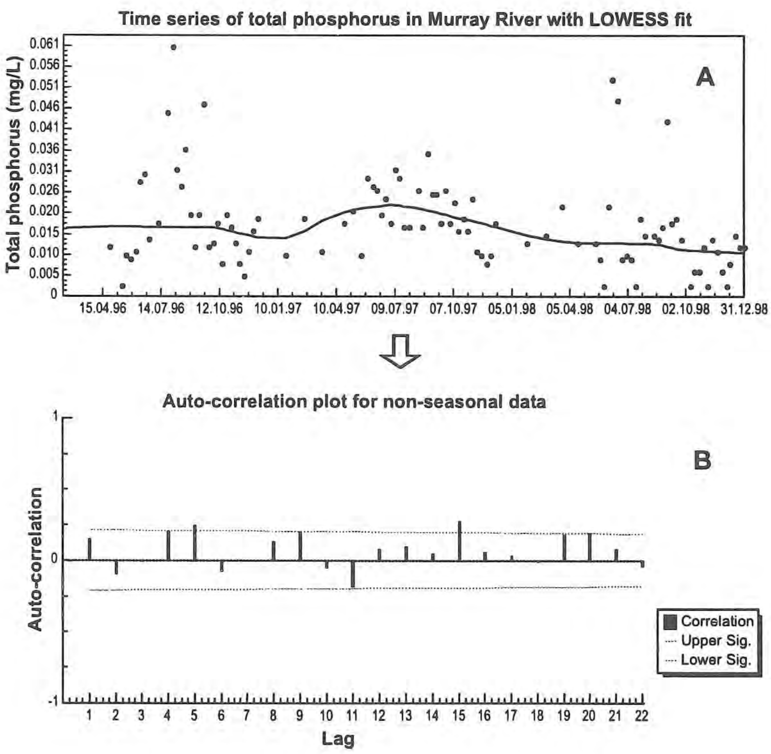

Figure 2: An example of a time series with little evidence of a seasonal pattern in total phosphorus concentration (A). The auto-correlation plot shows that the data in the time series is independent of each other (B). Hence, the Mann Kendall test for trend is used.

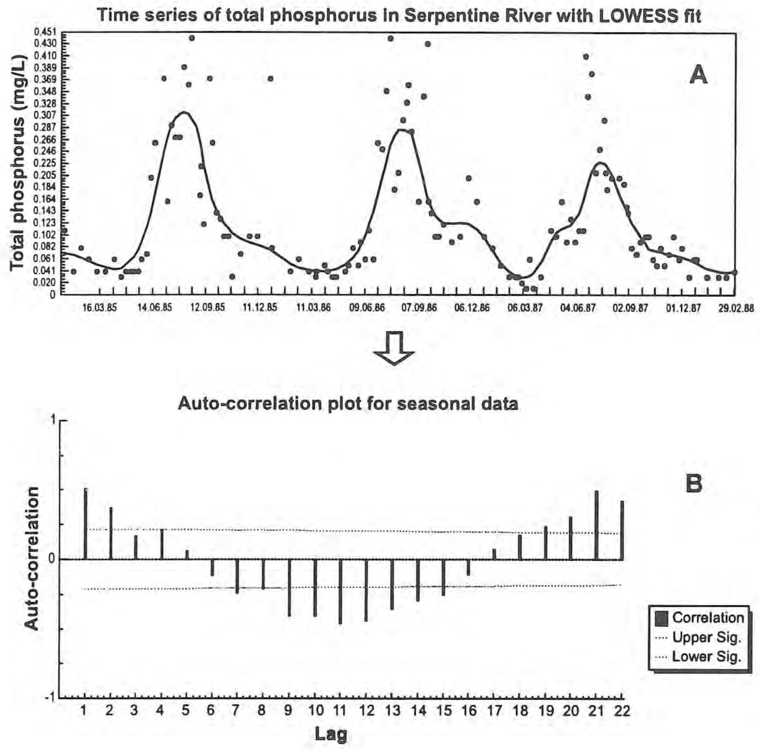

Figure 3: An example of a time series with a pronounced seasonal pattern in total phosphorus concentration (A). The auto-correlation plot shows an oscillating seasonal pattern and indicates that the data is dependent or contains memory (B). Hence, the Seasonal Kendall test for trend is used.

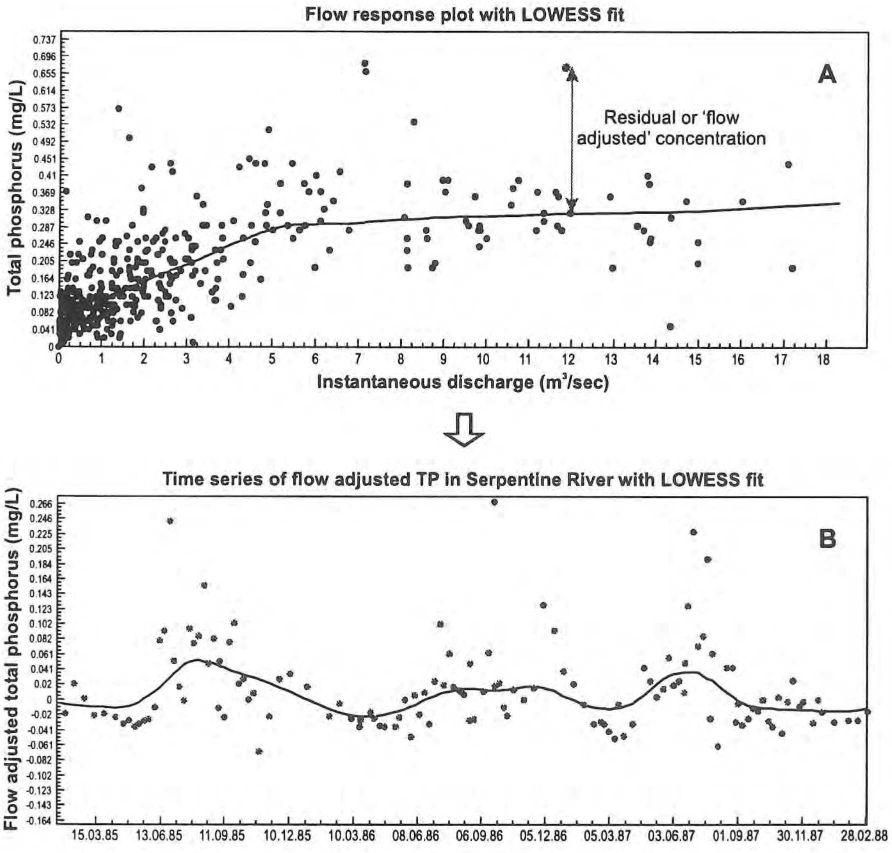

Figure 4: The flow response plot shows whether a relationship exists between discharge and nutrient concentration (A). If a relationship was evident (as in A) the series were adjusted for the effects of flow. The flow-adjusted concentrations (or residuals) were calculated as difference between observed and modelled (LOWESS) concentrations. Flow adjustment processes tend to remove the effects of flow from the data, the effects of which can be shown by comparing Figure 3A with Figure 4B.

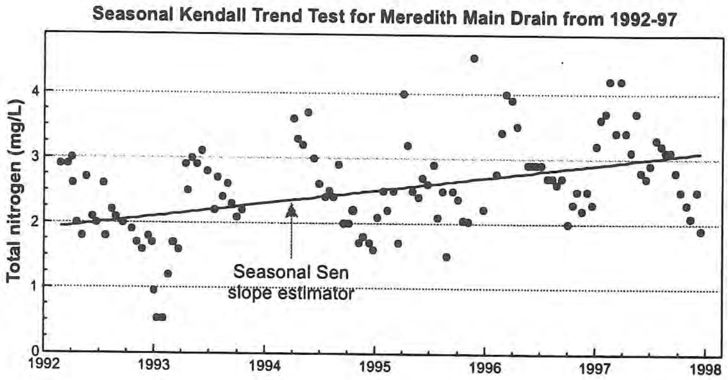

Figure 5: An example of how the Seasonal Sen slope estimator represents the slope of the trend line in a seasonal nutrient data series. The Seasonal Kendall test found the trend to be significant ($Z = 6.48$; $p < 0.001$) and possessed the required number of independent samples. The Seasonal Sen slope estimator showed that total nitrogen concentration increased by an estimated + 0.20 mg/L ever year between 1993 and 1997.

2.2.5 Sample size estimates

A period of change was found to be statistically significant when the Kendall Test had a p-value less than or equal to 0.05. This was not enough evidence to conclude a trend was present. *'A-posteriori'* calculations were subsequently carried out to assess whether enough independent samples had been collected and used in the trend test to meet the criteria specified by the nominated statistical error risks ($\alpha = 0.05$ and $\beta = 0.10$). This was achieved by comparing the effective information content in the collected data series with the number of independent samples required to detect a trend.

The effective information content in the data series, that is the effective number of independent values, was estimated for each of the data series analysed for trend using the formula provided by Bayly and Hammersley (1946) (*op cit* Lettenmaier, 1976; Lachance, 1992; Close, 1989; Zhou, 1996):

$$n^* = [1/n + 2/n^2 \sum_{j=1}^{n-1} (n - j)\, \rho\, (jt)]^{-1}$$

where:

n^* = effective number of independent observations

n = number of samples

j = lag number

t = sampling interval

ρ = coefficient of correlation

Where seasonal cycles were found the nutrient data series were de-trended and de-seasonalised (using seasonal medians) prior to calculating the number of independent samples (n^*).

The estimated number of samples needed to detect a linear trend (in a variable distributed normally about the trend line) was estimated using the function (Lettermaier, 1976; Ward *et al.*, 1990):

$$n^{\#} = 12\, \sigma^2 [\, t_{\alpha/2,(n-2)} + t_{\beta,(n-2)} \,]^2/\Delta^2$$

where:

$n^{\#}$ = estimated number of samples needed to detect a trend

σ = the standard deviation of the de-trended series

Δ = the magnitude of the trend

t = the critical values of the t-distribution, using $\alpha = 0.05$ and $\beta = 0.1$

This function relies on probabilities predicted by the t-distribution and is therefore from the parametric family of statistical procedures. Data requirements for parametric and the equivalent non-parametric tests are similar, so the equation will approximate the sample size needed for non-parametric tests of significance (Ward *et al.*, 1990).

2.2.6 Detecting the trend

A trend in the nutrient data series was detected only when two criteria were met. Firstly, the Kendall test for trend on the data series must be statistically significant (i.e. $p < 0.05$). Secondly, the number of independent samples collected (n^*) had to approximately equal or exceed the 'estimated' number of independent samples ($n\#$) required to detect a trend. The direction of a detected trend either increases (representing a deterioration of water quality) or decreases (representing an improvement in water quality).

When a statistically significant ($p < 0.05$) change in the nutrient data series occurred over the most recent period of interest, but too few independent samples were collected to detect a trend, the change was labelled as an emerging trend. The emerging trend makes the assumption that if the rate of change, variation and sampling frequency remain constant over the next five years a trend is likely to be detected. The emerging trend follows the philosophy of the 'precautionary principle', which is to err on the side of caution when there is doubt about potential adverse environmental effects. As an example of its application, an increasing trend infers "there is a problem", whereas the increasing emerging trend infers "if things stay the same, it is likely there will be a problem". This form of modelling enables managers to predict, plan, and act before adverse environmental impacts are detected. It must be reinforced however, that monitoring must continue to statistically confirm the presence of trend in a data series.

2.3 Assessing the nutrient status

The current status of nutrient water quality at the monitored sites was described by assigning it to one of five nutrient classes. The classes range from low concentrations (representing little or no nutrient enrichment) to extreme concentrations (representing extreme nutrient enrichment) (Table 2). Depending on trends, chance sampling and sources of natural variation, the nutrient concentrations sampled from a monitored site will change across the nutrient classes over time.

Table 2: The various classifications used to assess the status of total nitrogen (TN) and total phosphorus (TP) concentrations in a monitored waterway. The median concentration over a three year running period was used to determine the status.

TN		TP	STATUS
> 4.0 mg/L	extreme	> 0.5 mg/L	extremely enriched
3.0 - 4.0 mg/L	very high	0.3 - 0.5 mg/L	highly enriched
2.0 - 3.0 mg/L	high	0.2 - 0.3 mg/L	enriched
1.0 - 2.0 mg/L	moderate	0.1 - 0.2 mg/L	mildly enriched
< 1.0 mg/L	low	< 0.1 mg/L	close to natural

For this report, a nutrient class for a waterway was assigned by using a median nutrient concentration (a measure of central tendency) over a three-year running period. The three-year period is used to diminish the influence of natural variation between years. The most recent period of analysis (1996-98 for this report) was used to determine each monitored site's current nutrient status. A current status was not assigned to the site when no samples were collected during the 1996-98 monitoring period.

Figure 6 shows an example of the method used to determine nutrient class or status over the monitoring period. The initial class of very high was determined on 'face-value' where the median TP concentration for the 1987 period was used. Subsequent classes were determined using 90 percent confidence intervals and (generally) three year periods to remove the influence of wet and dry years. Median TP concentrations decreased in the 1987-88 and 1987-89 periods but the confidence intervals still remained within the very high class. In the 1988-90 period both the median TP concentration and the 90% confidence interval fell below the high/very high boundary limit of 0.30 mg/L. Thus it is 95% certain that the median TP concentration is less than 0.3 mg/L and consequently the class or status is changed to high. The classification scheme continues for each three year running period thereafter, only changing when there is at least 95% certainty that the median concentration has moved into a new class.

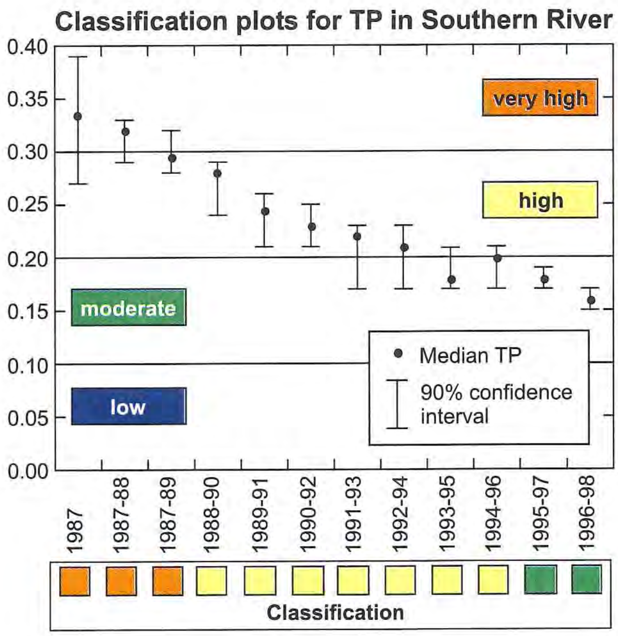

Figure 6: An example of how the classification scheme is used to derive a nutrient status using running three year periods. The classification boundaries for TP concentrations are shown for low, moderate, high and very high classes. The classification bar at the bottom of the figure shows the class or status assigned to each period over the monitoring period using the median and confidence intervals.

3. Results

This section presents the results of status and trend tests for each monitored site in the Peel-Harvey catchment monitoring program.

For the purposes of this report, the monitored sites were grouped into four broad regions. These included the Serpentine region, the Murray region, the Harvey region and the region comprised of the drains that discharge directly to the Peel Inlet and Harvey estuary (Figure 1).

3.1 Serpentine region

The Serpentine region encompasses the catchments of the Serpentine River and its tributaries.

3.1.1 Serpentine River

Current Total Nitrogen Status: Low

The median TN concentration in the Serpentine River over the monitoring period was 1.1 mg/L, with annual median TN concentrations ranging between 0.8 mg/L (1998) and 2.7 mg/L (1988). The minimum TN concentration sampled was 0.2 mg/L and the maximum was 6.12 mg/L over the duration of monitoring. The data was highly seasonal and consequently the Seasonal Kendall test for trend was used. Total nitrogen concentrations in the Serpentine River were responsive to flow and the data was subsequently adjusted. Trend results indicate that total nitrogen concentrations in the river have not changed appreciably over the 1985-98 monitoring period (Figure 7; Table 3).

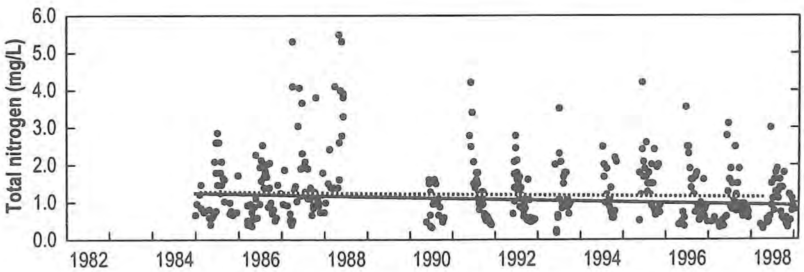

Figure 7: Time series of observed (black line) and flow-adjusted (dotted line) total nitrogen for Serpentine River over the period 1985-98.

Current Total Phosphorus Status: Moderate

The median TP concentration in the Serpentine River over the monitoring period was 0.14 mg/L, with annual median TP concentrations ranging between 0.09 mg/L (1987) and 0.25 mg/L (1984 and 1992). The minimum TP concentration sampled was 0.01 mg/L and the maximum was 1.1 mg/L. The data did not show evidence of a seasonal pattern and thus the Mann Kendall test for trend was used. The TP concentrations were responsive to flow and the data was subsequently adjusted for the effects of flow. There was no evidence of trend for total phosphorus concentrations in the Serpentine over the 1983-98 monitoring period (Figure 8; Table 3).

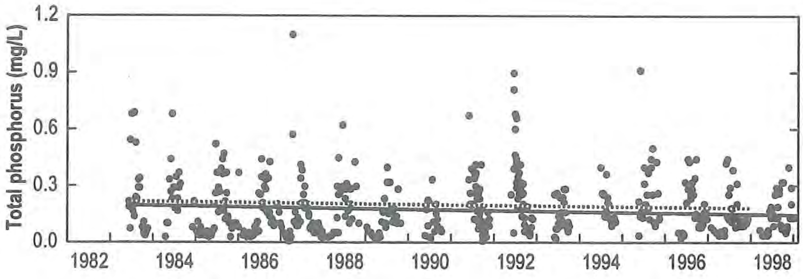

Figure 8: Time series of observed (black line) and flow-adjusted (dotted line) total phosphorus for Serpentine River over the period 1983-98.

Table 3: Results of statistical analysis for trend tests in Serpentine River. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1985-98	obs	SK	-0.007	-1.029	0.303	289	114	7280	No trend
	1985-97	FAC	SK	-0.005	-0.572	0.452	267	105	10780	No trend
TP	1983-98	obs	MK	-0.004	-2.727	0.006	360	215	547	No trend
	1983-97	FAC	MK	-0.003	-2.712	0.007	338	141	589	No trend

3.1.2 Peel Main Drain

Current Total Nitrogen Status: (not applicable)

Peel Main Drain was monitored for four years between 1990-93. The median TN concentration during was 2.0 mg/L, with annual medians ranging between 1.6 mg/L (1990) and 2.18 mg/L (1991). The minimum TN concentration sampled was 0.41 mg/L and the maximum was 12.6 mg/L. The data was not seasonal and did not exhibit a relationship with flow. The trend results showed no evidence of trend in TN concentrations in Peel Main Drain over the monitoring period (Figure 9; Table 4).

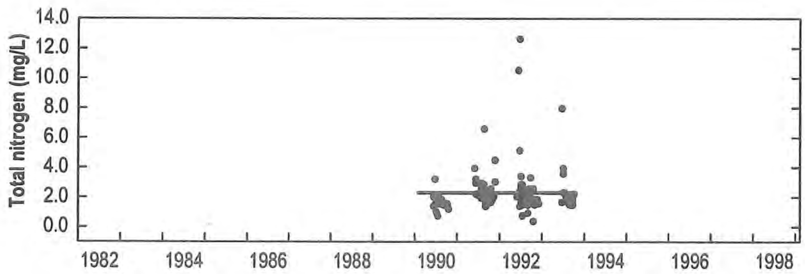

Figure 9: Time series of observed total nitrogen for Peel Main Drain over the period 1990-93.

Current Total Phosphorus Status: (not applicable)

The median TP concentration in Peel Main Drain was 0.27 mg/L over the 1990-93 monitoring period. The annual median TP concentration ranged between 0.19 mg/L (1993) and 0.31 mg/L (1992). The extremes in TP concentrations sampled ranged between a minimum of 0.02 mg/L and a maximum of 1.23 mg/L. The data was not seasonal thus the Mann Kendall test for trend was used. Total phosphorus concentrations in Peel Main Drain were related to flow and the data was subsequently adjusted. The trend results indicated a decreasing trend of -0.08 mg/L/yr in flow-adjusted TP between 1990-93. The trend is large and must be interpreted with caution as the rate of change may be exaggerated due to the relatively short period of analysis. The reintroduction of monitoring at the Peel Main Drain site may provide an indication of whether TP concentrations continued to decline or remained steady (Figure 10; Table 4).

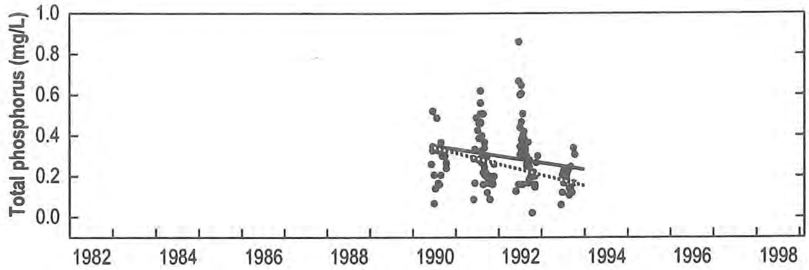

Figure 10: Time series of observed (black line) and flow-adjusted (dotted line) total phosphorus for Peel Main Drain over the period 1990-93.

Table 4: Results of statistical analysis for trend tests in Peel Main Drain. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-93	obs	MK	0	-0.128	0.898	118	75		No trend
TP	1990-93	obs	MK	-0.038	-2.828	0.005	118	54	65	No trend
	1990-93	FAC	MK	-0.081	-5.485	<0.001	8952	10		Decreasing trend

3.1.3 Dirk Brook/Punrack Drain

Current Total Nitrogen Status: Moderate

The overall median TN concentration was 1.0 mg/L for Dirk Brook, with annual median concentrations ranging between 0.73 mg/L (1990) and 1.4 mg/L (1996). The extremes in TN concentration over the 1990-98 monitoring period ranged from a minimum of 0.31 mg/L to a maximum of 16.47 mg/L. The data was not seasonal and did not exhibit a relationship with flow. The data did not show any evidence of seasonal patterns and thus the Mann Kendall test for trend was used. There was no evidence of trend in the TN concentration data series in Dirk Brook over the monitoring period (Figure 11; Table 5).

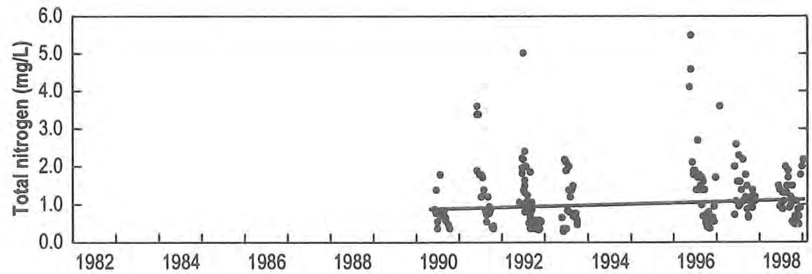

Figure 11: Time series of observed total nitrogen for Dirk Brook over the period 1990-98.

Current Total Phosphorus Status: Moderate

The overall median TP concentration was 0.14 mg/L for Dirk Brook, with annual median concentrations ranging between 0.05 mg/L (1990) to 0.21 mg/L (1998). Extreme TP concentrations ranged from a minimum of 0.02 mg/L to a maximum of 3.6 mg/L. The data was not seasonal, but did show a relationship with flow. There was no evidence of trend in the TP concentration data series in Dirk Brook during the 1990-98 monitoring period. There was some evidence to suggest a step change has occurred between the two sub-periods with an increase in the distribution and variance of the TP concentration data. The absence of data collected in 1994-95 meant that a trend could not be detected and the nature of the source could not be determined (Figure 12; Table 5).

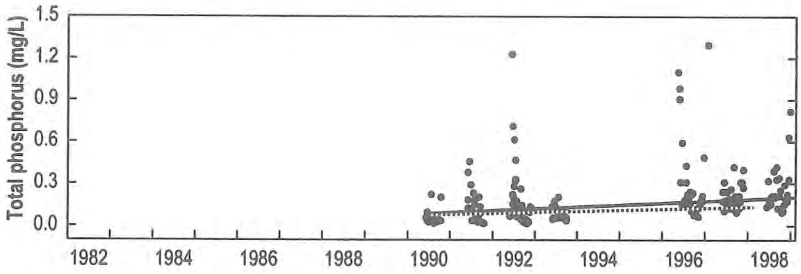

Figure 12: Time series of observed (black line) and flow-adjusted (dotted line) total phosphorus for Dirk Brook over the period 1990-98.

Table 5: Results of statistical analysis for trend tests in Dirk Brook. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	MK	0.015	1.038	0.299	162	64	14507	No trend
TP	1990-98	obs	MK	0.011	4.580	<0.001	162	68	274	No trend
	1990-97	FAC	MK	0.009	3.485	<0.001	142	58	384	No trend

3.1.4 Gull Road Drain

Current Total Nitrogen Status: Extreme

Gull Road Drain had an overall median TN concentration of 7.4 mg/L for the grab samples, with annual median concentrations ranging between 4.58 mg/L (1995) and 29 mg/L (1993). The extremes of TN concentrations sampled varied between a minimum of 0.58 mg/L and a maximum of 67 mg/L. Total nitrogen concentrations in the drain are unusually high indicating that a point source is heavily influential. The elevated TN concentrations in the baseflows suggest that groundwater sources may also be polluted or that the point source is providing the bulk of flow to the drain. The data was not seasonal and thus the Mann Kendall test was used. Flow was not monitored in the drain over the monitoring period, which inhibited the flow-adjustment process. The trend tests on the grab sample data indicate that there was no trend in the TN data series, but this may have been complicated by the fact that the series was not monotonic (Figure 13; Table 6).

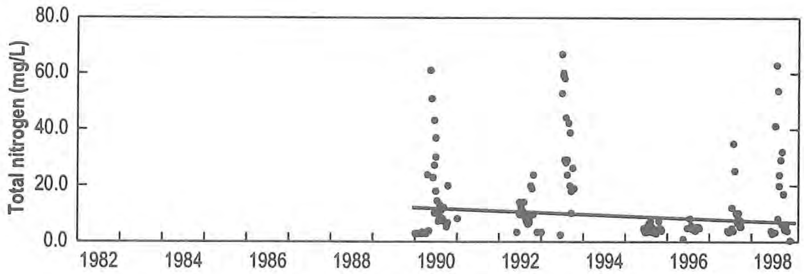

Figure 13: Time series of observed total nitrogen for Gull Rd Drain over the period 1990-98.

Current Total Phosphorus Status: Extreme

The overall median TP concentration for Gull Road Drain was 3.8 mg/L, with annual median concentrations ranging between 2.0 mg/L (1998) and 7.25 mg/L (1993). Extremes in TP concentration varied between a minimum of 0.05 mg/L and a maximum of 18 mg/L. Total phosphorus concentrations in the drain were also unusually high, again supporting the heavy influence of a point source. The data was not seasonal and the lack of flow data prevented the flow-adjustment process. The trend tests indicate that TP concentrations have remained steady over the monitoring period, although the tests may have been complicated by the fact that the series was not monotonic (Figure 14; Table 6).

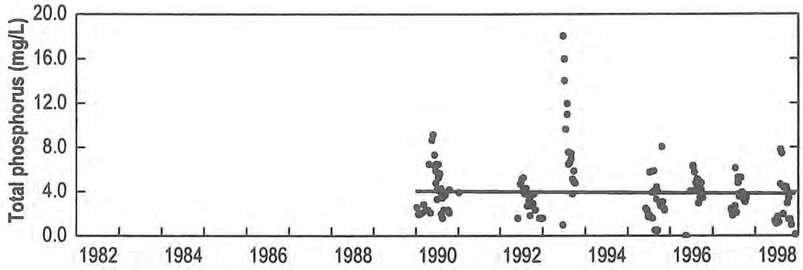

Figure 14: Time series of observed total phosphorus for Gull Rd Drain over the period 1990-98.

Table 6: Results of statistical analysis for trend tests in Gull Road Drain. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	MK	-0.5	-2.275	0.023	130	27	1178	No trend
TP	1990-98	obs	MK	0	0	1	130	33		No trend

3.1.5 Nambeelup Brook

Current Total Nitrogen Status: High

The overall median TN concentration in Nambeelup Brook was 2.6 mg/L over the 1990-98 monitoring period. Annual median concentrations ranged between 1.85 mg/L (1990) to 3.0 mg/L (1997). The minimum recorded TN concentration was 0.71 mg/L and the maximum was 6.0 mg/L. The data was seasonal and thus the Seasonal Kendall test for trend was used. There was no relationship between TN concentration and flow. The trend tests showed a large increasing trend of +0.133 mg/L/yr in Nambeelup Brook over the 1990-98 monitoring period (Figure 15; Table 7).

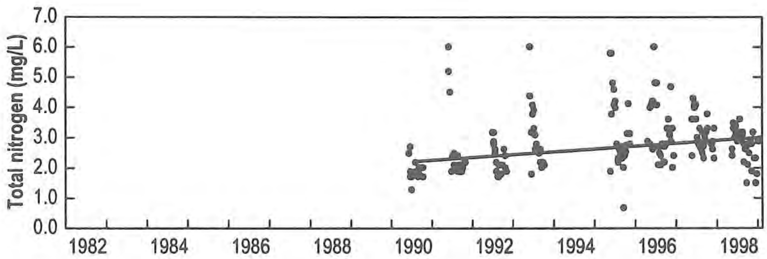

Figure 15: Time series of observed total nitrogen for Nambeelup Brook over the period 1990-98.

Current Total Phosphorus Status: Extreme

The overall median TP concentration in Nambeelup Brook was 0.57 mg/L over the 1990-98 monitoring period. Annual median concentrations ranged between 0.37 mg/L (1990) and 0.68 mg/L (1995 and 1997). The minimum recorded TP concentration was 0.12 mg/L and the maximum was 1.5 mg/L, the latter figure suggesting the presence of a phosphorus point source. The data was seasonal and there was no relationship observed between TP concentration and flow. A large increasing trend of +0.042 mg/L was found in Nambeelup Brook over the 1990-98 monitoring period (Figure 16; Table 7).

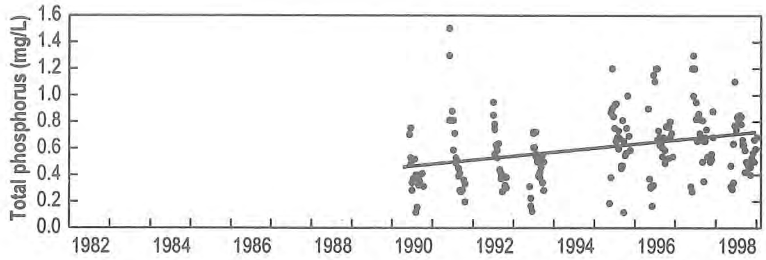

Figure 16: Time series of observed total phosphorus for Nambeelup Brook over the period 1990-98.

Table 7: Results of statistical analysis for trend tests in Nambeelup Brook. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	SK	0.133	7.297	<0.001	160	95	52	Increasing trend
TP	1990-98	obs	SK	0.042	7.381	<0.001	160	103	45	Increasing trend

3.2 Murray region

The Murray region encompasses the catchments of the Murray River and its tributaries.

3.2.1 Murray River

Current Total Nitrogen Status: Low

The overall median TN concentration in the Murray River was 0.75 mg/L, with annual medians varying between 0.47 mg/L (1998) and 1.47 mg/L (1988). The minimum TN concentration recorded was 0.09 mg/L and the maximum was 13 mg/L. In general the data was not seasonal, although recent monitoring shows evidence of a pronounced seasonal pattern in the TN data. Flow data has only been collected since 1993 and thus the data was not flow-adjusted. The trend tests indicated that TN concentrations in the Murray River have not changed appreciably over the 1983-98 monitoring period (Figure 17; Table 8). Missing data for 1989, 1994 and 1995 may have compromised the trend test. Figure 17 suggests that variation in nitrogen concentrations has probably decreased over the monitoring period but this may be attributed to the use of various sampling regimes.

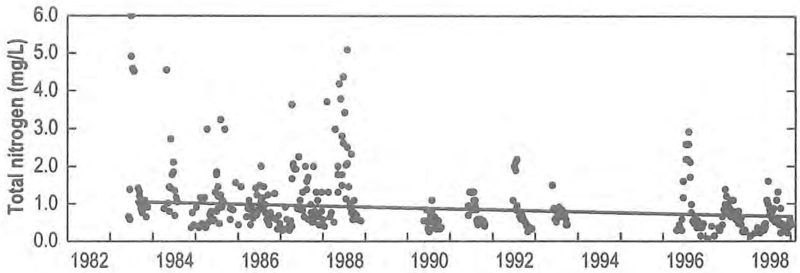

Figure 17: Time series of observed total nitrogen for Murray River over the period 1983-98.

Current Total Phosphorus Status: Low

The median TP concentration in the Murray River over the 1983-98 monitoring period was 0.02 mg/L. Annual median concentrations ranged between 0.01 mg/L (1989, 1991-93) to 0.05 mg/L (1983). The minimum TP concentration recorded was <0.005 mg/L and the maximum was 0.38 mg/L. The data was not seasonal and the lack of flow data meant that flow adjustment was not performed. The trend test showed that TP concentrations in the Murray River have remained steady over the monitoring period (Figure 18; Table 8). There is again some evidence to suggest that variation in the phosphorus series has decreased; however this is probably reflecting a change in the sampling regimes used. Recent improvements in the phosphorus detection limits may complicate the interpretation of future trend tests.

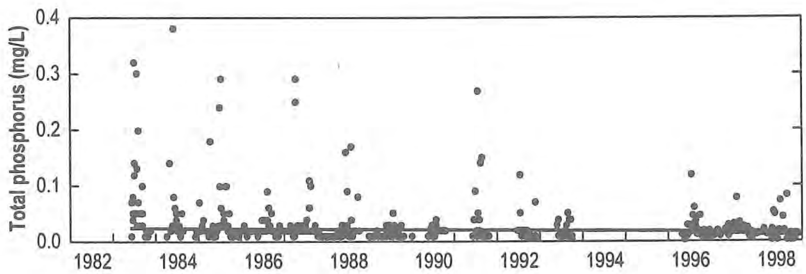

Figure 18: Time series of observed total phosphorus for Murray River over the period 1983-98.

Table 8: Results of statistical analysis for trend tests in Murray River. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1983-98	obs	MK	-0.031	-5.494	<0.001	255	67	330	No trend
TP	1983-98	obs	MK	-0.001	-6.665	<0.001	289	208	835	No trend

3.2.2 South Dandalup River

Current Total Nitrogen Status: Low

The overall median TN concentration for South Dandalup River over the 1990-98 monitoring period was 0.43 mg/L. Annual median concentrations ranged between 0.29 mg/L (1992) to 0.66 mg/L (1997). Extremes in TN concentration varied from a minimum of 0.09 mg/L to a maximum of 3.0 mg/L. Total nitrogen concentrations in the river were seasonal and thus the Seasonal Kendall test for trend was used. The gauging station was decommissioned in February 1996 so recent flow data was unavailable for flow adjusting the data. An increasing trend of +0.072 mg/L./yr in TN concentration was found in South Dandalup River over the 1990-98 monitoring period (Figure 19; Table 9). The trend is attributed to an increase in the variation rather than a shift in the TN concentration distribution over time. This suggests that the cause is probably due to an increase in the nitrogen in surface/sub-surface run-off generated from winter rains. This effect would be seen in areas recently cleared of remnant vegetation.

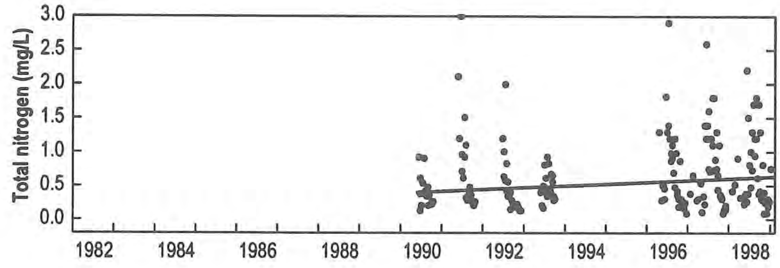

Figure 19: Time series of observed total nitrogen for South Dandalup River over the period 1990-98.

Current Total Phosphorus Status: Low

The overall median TP concentration for South Dandalup River over the 1990-98 monitoring period was 0.05 mg/L. Annual median concentrations ranged between 0.02 mg/L (1990 and 1993) to 0.06 mg/L (1997 and 1998). Extremes in TP concentration varied from a minimum concentration of 0.01 mg/L to a maximum of 0.48 mg/L. The data was not seasonal and was not adjusted for flow-effects since the gauging station was decommissioned in 1996. The trend test indicated that an increasing emerging trend is present in TP concentrations for South Dandalup River (Figure 20; Table 9). There appears to be evidence of an increase in variation over the monitoring period, but the lack of sample data in 1994-95 hindered the trend test. Further monitoring is required to confirm the presence of an increasing trend in phosphorus.

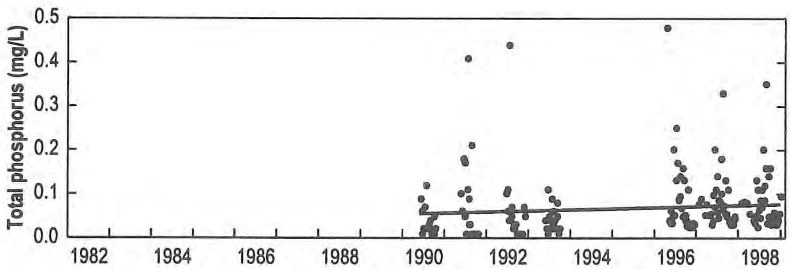

Figure 20: Time series of observed total phosphorus for South Dandalup River over the period 1990-98.

Table 9: Results of statistical analysis for trend tests in South Dandalup River. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	SK	0.072	6.152	<0.001	141	78	77	Increasing trend
TP	1990-98	obs	MK	0.005	4.609	<0.001	141	133	237	Emerging increase

3.3 Drains to the estuaries

This region is described by the catchments of several drains that discharge directly to the Peel Inlet and Harvey Estuary.

3.3.1 Caris Drain

Current Total Nitrogen Status: Moderate

The overall median TN concentration was 1.8 mg/L for Caris Drain over the 1990-98 monitoring period. Annual median concentrations ranged between 1.40 mg/L (1990 and 1998) to 2.0 mg/L (1997). The minimum TN concentration sampled was 0.55 mg/L and the maximum was 7.3 mg/L. The data was not seasonal and was not responsive to flow. Trend tests indicate that TN concentrations in Caris Drain have not changed over the duration of monitoring (Figure 21; Table 10).

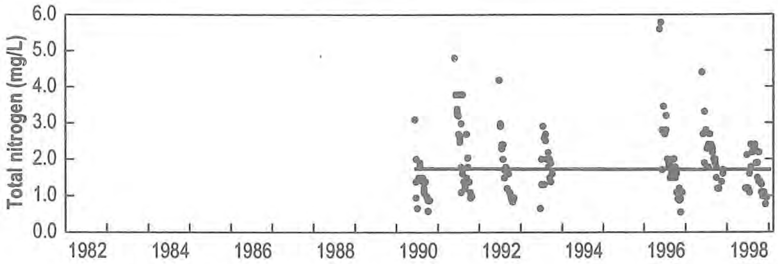

Figure 21: Time series of observed total nitrogen for Caris Drain over the period 1990-98.

Current Total Phosphorus Status: Moderate

Caris Drain had an overall median TP concentration of 0.12 mg/L, with annual median concentration ranging between 0.05 mg/L (1990) and 0.16 mg/L (1991 and 1996). Extremes in TP concentration varied between a minimum of 0.01 mg/L and a maximum of 0.48 mg/L. The data was not seasonal, but did show a relationship with flow and subsequently the data was adjusted for the effects of flow. An increasing trend of +0.012 mg/L/yr was detected for TP in Caris Drain over the 1990-98 monitoring period (Figure 22; Table 10). The trend is probably due to a gradual rise in diffuse phosphorus contributions over time.

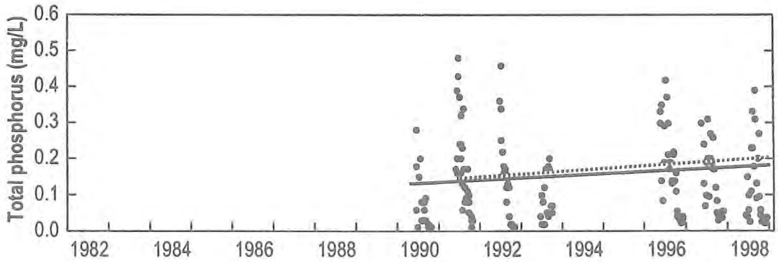

Figure 22: Time series of observed (black line) and flow-adjusted (dotted line) total phosphorus for Caris Drain over the period 1990-98.

Table 10: Results of statistical analysis for trend tests in Caris Drain. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	MK	0	0.498	0.618	143	72		No trend
TP	1990-98	obs	MK	0.009	4.222	<0.001	143	87	203	Emerging increase
	1991-98	FAC	MK	0.012	4.331	<0.001	125	111	77	Increasing trend

3.3.2 Coolup Main Drain

Current Total Nitrogen Status: High

The overall median TN concentration was 1.90 mg/L for Coolup Main Drain over the 1990-98 monitoring period. Annual median concentrations ranged from 1.40 mg/L (1990 and 1993) to 2.10 mg/L (1992 and 1997). Extreme TN concentrations ranged between a minimum of 0.38 mg/L and a maximum of 4.54 mg/L. The data was not seasonal and did not show a relationship with flow. The trend test showed that TN concentrations in the drain have not changed over the monitoring period (Figure 23; Table 11).

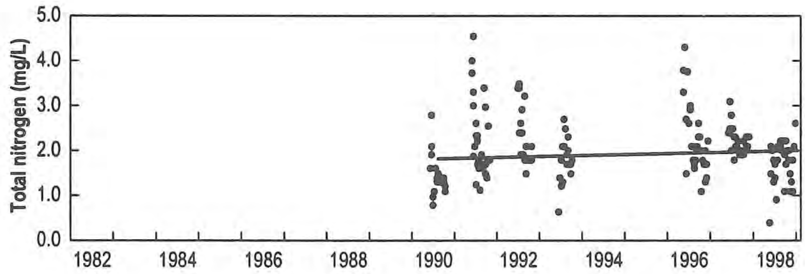

Figure 23: Time series of observed total nitrogen for Coolup Main Drain over the period 1990-98.

Current Total Phosphorus Status: High

The overall median TP concentrations in Coolup Main Drain was 0.25 mg/L, with annual medians ranging from 0.18 mg/L (1990 and 1993) to 0.42 mg/L (1992). Extreme TP concentrations ranged between a minimum of 0.03 mg/L and a maximum of 0.79 mg/L. The data was seasonal and therefore the Seasonal Kendall test for trend was used. The data was also responsive to flow and was subsequently flow-adjusted. The trend test showed that there was no evidence of change in the TP data series in Coolup Main Drain over the 1990-98 monitoring period (Figure 24; Table 11).

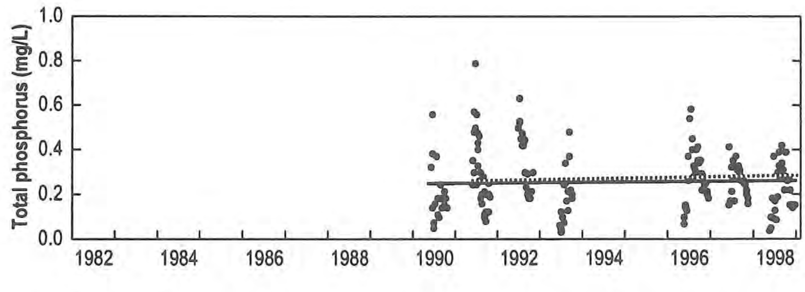

Figure 24: Time series of observed (black line) and flow-adjusted (dotted line) total phosphorus for Coolup Main Drain over the period 1990-98.

Table 11: Results of statistical analysis for trend tests in Coolup Main Drain. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	MK	0.024	1.708	0.088	241	215	1201	No trend
TP	1990-90	obs	SK	0.010	2.714	0.007	149	37	337	No trend
	1991-98	FAC	SK	0.011	2.275	0.023	130	39	232	No trend

3.3.3 Mealup Main Drain

Current Total Nitrogen Status: Very High

Monitoring at the Mealup Main Drain site commenced in 1996. The median TN concentration over the three years was 3.0 mg/L, with a minimum sampled concentration of 1.9 mg/L and a maximum of 9.6 mg/L (Figure 25). Trend results for Mealup Main Drain will be first available in 2001 when five years of data becomes available for analysis.

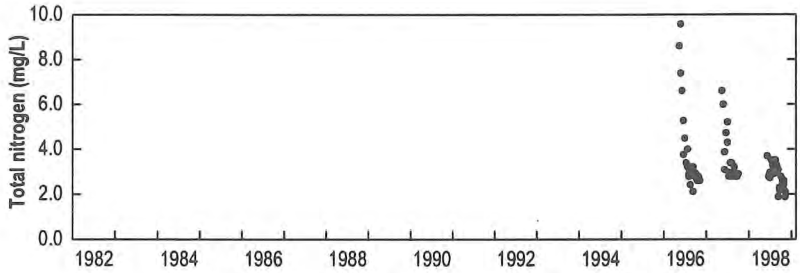

Figure 25: Time series of observed total nitrogen for Mealup Main Drain over the period 1996-98.

Current Total Phosphorus Status: Extreme

The median TP concentration for the 1996-98 monitoring period was 0.13 mg/L, with extremes ranging between a minimum of 0.01 mg/L and a maximum of 1.56 mg/L (Figure 26). Trend results will first become available in 2001.

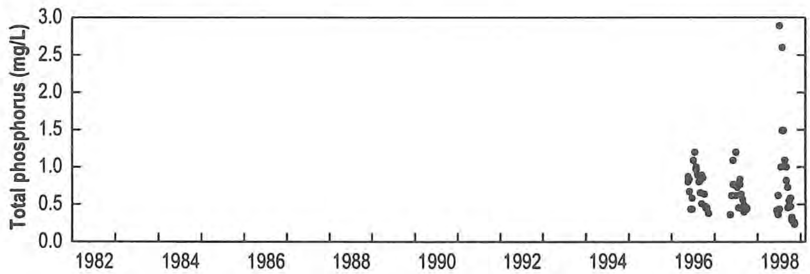

Figure 26: Time series of observed total phosphorus for Mealup Main Drain over the period 1996-98.

3.3.4 South Coolup Main Drain

Current Total Nitrogen Status: Moderate

The overall median TN concentration for South Coolup Main Drain was 1.60 mg/L over the 1990-98 monitoring period. Annual median concentrations ranged from 1.35 mg/L (1990) to 1.85 mg/L (1991). The minimum sampled TN concentration was 0.49 mg/L and the maximum sampled TN concentration was 5.0 mg/L. The observed data showed evidence of seasonal patterns, but when the data was adjusted for the effects of flow the seasonal pattern was no longer present. An emerging increasing trend was apparent in the flow-adjusted TN data, but this requires further monitoring to confirm a trend (Figure 27; Table 12).

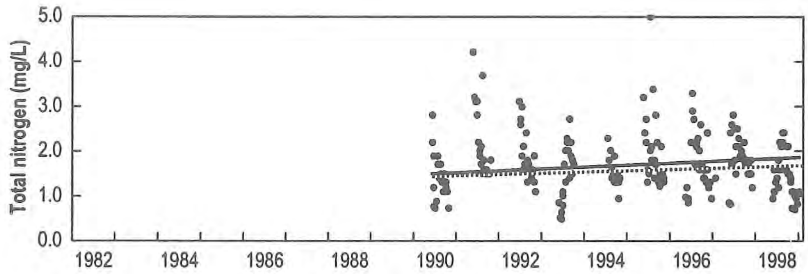

Figure 27: Time series of observed (black line) and flow-adjusted (dotted line) total nitrogen for South Coolup Main Drain over the period 1990-98.

Current Total Phosphorus Status: Very High

The overall median TP concentration in South Coolup Main Drain was 0.32 mg/L, with annual medians varying between 0.15 mg/L (1993) and 0.39 mg/L (1996 and 1997). Extremes in TP concentrations sampled ranged from 0.01 mg/L to 1.0 mg/L. The observed data showed evidence of seasonal patterns, but when the data was adjusted for the effects of flow the seasonal pattern was no longer present. An emerging increasing trend was present in the flow-adjusted TP data, but this requires continued monitoring to confirm a trend (Figure 28; Table 12).

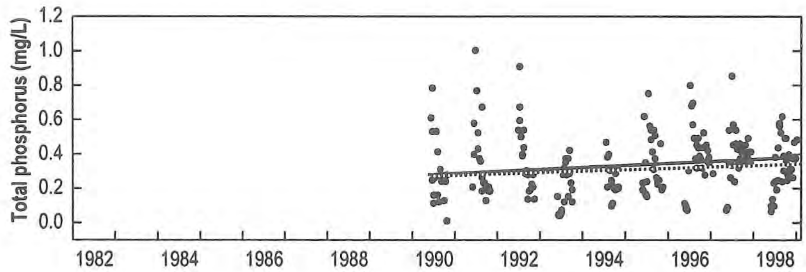

Figure 28: Time series of observed (black line) and flow-adjusted (dotted line) total phosphorus for South Coolup Main Drain over the period 1990-98.

Table 12: Results of statistical analysis for trend tests in South Coolup Main Drain. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	SK	0.05	3.731	<0.001	179	111	313	Emerging increase
	1990-98	FAC	MK	0.033	2.791	0.005	179	106	390	Emerging increase
TP	1990-98	obs	SK	0.018	4.306	<0.001	179	98	194	Emerging increase
	1990-98	FAC	MK	0.013	3.708	<0.001	179	69	151	Emerging increase

3.4 Harvey region

The Harvey region encompasses the catchments of the Harvey River and its tributaries.

3.4.1 Mayfields Main Drain

Current Total Nitrogen Status: Low

The overall median TN concentration in Mayfields Main Drain was 1.10 mg/L over the 1990-98 monitoring period. Annual median concentrations ranged from 0.53 mg/L (1998) to 1.5 mg/L (1991). Extremes in TN concentration ranged from a minimum of 0.16 mg/L to a maximum of 5.8 mg/L. The data was highly seasonal, with low TN concentrations in baseflows and elevated TN concentrations during winter. The data was flow responsive and subsequently flow-adjusted. The adjusted data still had evidence of seasonal patterns and thus the Seasonal Kendall test was used. The trend tests showed that TN concentrations have not changed over the monitoring period (Figure 29; Table 13).

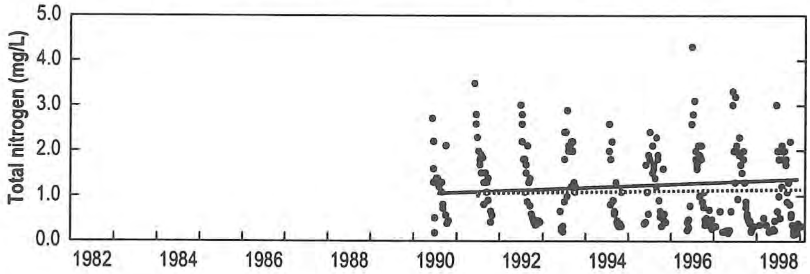

Figure 29: Time series of observed (black line) and flow-adjusted (dotted line) total nitrogen for Mayfields Main Drain over the period 1990-98.

Current Total Phosphorus Status: Low

The overall median TP concentration in Mayfields Main Drain was 0.08 mg/L over the 1990-98 monitoring period. Annual median concentrations ranged from 0.03 mg/L (1998) to 0.17 mg/L (1992). Extreme concentrations sampled in the drain varied from a minimum of < 0.005 mg/L to a maximum of 0.80 mg/L over the monitoring period. The data was highly seasonal and still contained a seasonal pattern after the data was adjusted for the effects of flow. The trend tests indicate that TP concentrations in Mayfields Main Drain have remained steady over the monitoring period (Figure 30; Table 13).

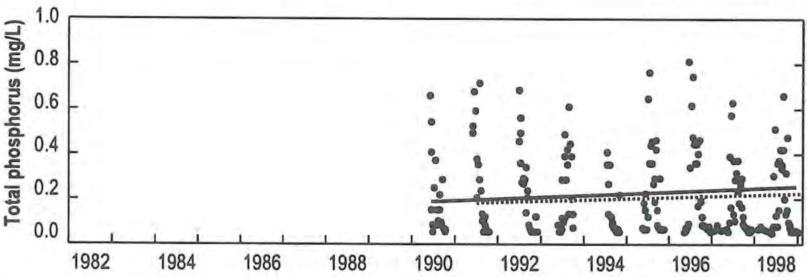

Figure 30: Time series of observed (black line) and flow-adjusted (dotted line) total phosphorus for Mayfields Main Drain over the period 1990-98.

Table 13: Results of statistical analysis for trend tests in Mayfields Main Drain. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	SK	0.046	2.786	0.005	180	119	488	No trend
	1991-98	FAC	SK	0.005	2.396	0.017	161	75	990	No trend
TP	1990-98	obs	SK	0.008	3.476	0.001	180	106	897	No trend
	1991-98	FAC	SK	0.005	2.396	0.017	161	75	990	No trend

3.4.2 Mayfields Main Drain—SubG

Current Total Nitrogen Status: (not applicable)

The sub G branch of Mayfields Main Drain was only monitored between 1990-93. The overall median TN concentration for the period was 2.20 mg/L, and extremes in concentrations ranged from a minimum of 0.96 to a maximum of 6.3 mg/L. The data was highly seasonal so the Seasonal Kendall test for trend was used. Flow was not monitored at this site. The results of the trend test over the four year period showed no evidence of change in TN concentrations (Figure 31; Table 14).

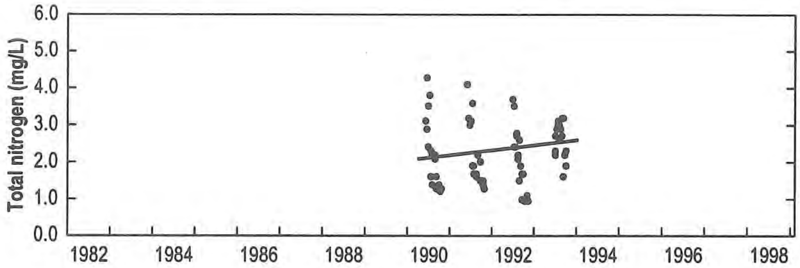

Figure 31: Time series of observed total nitrogen for Mayfields Main Drain—SubG over the period 1990-93.

Current Total Phosphorus Status: (not applicable)

The overall median TP concentration for the period was 0.25 mg/L and extremes in concentrations ranged from a minimum of 0.02 to a maximum of 1.0 mg/L. The data was highly seasonal so the Seasonal Kendall test for trend was used. Trend tests indicate that TP concentrations in the drain did not vary over the four year period (Figure 32; Table 14).

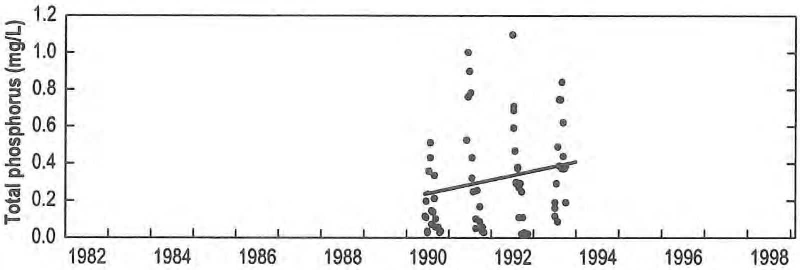

Figure 32: Time series of observed total phosphorus for Mayfields Main Drain—SubG over the period 1990-93.

Table 14: Results of statistical analysis for trend tests in Mayfields Main Drain—SubG . (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-93	obs	SK	0.20	2.078	0.038	69	65	162	No trend
TP	1990-93	obs	SK	0.05	2.727	0.006	69	23	187	No trend

3.4.3 Harvey River

Current Total Nitrogen Status: Moderate

The overall median TN concentration in the Harvey River over the 1983-98 monitoring period was 1.2 mg/L. Annual median concentrations varied from 0.88 mg/L (1994) to 2.75 mg/L (1988). Extreme TN concentrations sampled in the river varied from a minimum of 0.33 to a maximum of 5.90 mg/L. The TN data was highly seasonal so the Seasonal

Kendall was used. There was insufficient flow data available at the time of analysis to flow-adjust the entire data series. The trend results showed no evidence of trend in the TN concentration data series in the Harvey River over the monitoring period (Figure 33; Table 15).

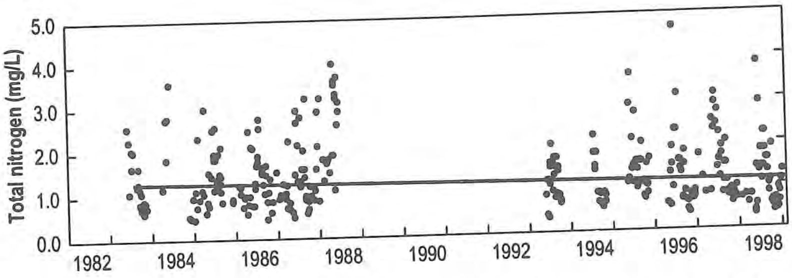

Figure 33: Time series of observed total nitrogen for Harvey River over the period 1983-98.

Current Total Phosphorus Status: Moderate

The overall median TP concentration in the Harvey River over the 1983-98 monitoring period was 0.15 mg/L. Annual median concentrations varied from 0.10 mg/L (1983) to 0.26 mg/L (1986). Extreme TP concentrations ranged between a minimum sampled concentration of 0.02 mg/L to a maximum of 0.62 mg/L. The phosphorus data was highly seasonal and thus the Seasonal Kendall test for trend was used. There was insufficient flow data available at the time of analysis to flow-adjust the entire data series. The trend results showed no evidence of trend in the TP concentration in the Harvey River over the monitoring period (Figure 34; Table 15).

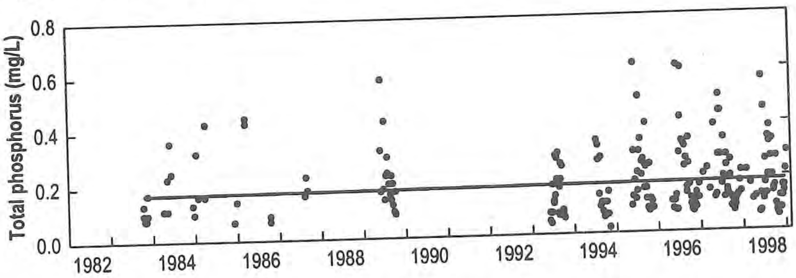

Figure 34: Time series of observed total phosphorus for Harvey River over the period 1982-98.

Table 15: Results of statistical analysis for trend tests in Harvey River. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1983-98	obs	SK	0	0.691	0.679	186	174		No trend
TP	1983-98	obs	SK	0.003	1.895	0.058	154	145	670	No trend

3.4.4 Samson Brook North

Current Total Nitrogen Status: Low

The overall median TN concentration for Samson Brook North over the 1990-98 monitoring period was 1.3 mg/L. Annual median concentrations varied from 0.31 mg/L (1993) to 2.0 mg/L (1997). Extremes in sampled TN concentrations varied from a minimum of 0.16 mg/L to a maximum of 8.1 mg/L. The data was seasonal and was not responsive to flow. Trend analysis showed evidence of an emerging increasing trend in TN concentration in Samson Brook; however more sampling is required to confirm the presence of a trend (Figure 35; Table 16).

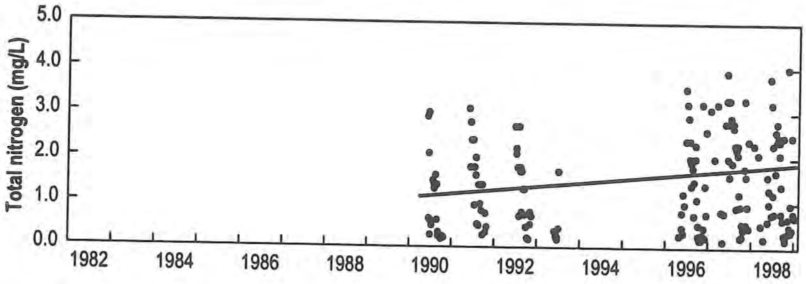

Figure 35: Time series of observed total nitrogen for Samson Brook North over the period 1990-98.

Current Total Phosphorus Status: Moderate

The overall median TP concentration for Samson Brook North over the 1990-98 monitoring period was 0.14 mg/L. Annual median concentrations varied from 0.05 mg/L (1990) to 0.21 mg/L (1997). Extremes in sampled TP concentrations varied from a minimum of 0.01 mg/L to a maximum of 1.30 mg/L. The TP data was seasonal but was not related to the effects of flow. Trend analysis showed evidence of an emerging increasing trend in TP concentrations in Samson Brook North; however more sampling is required to confirm the presence of a trend (Figure 36; Table 16).

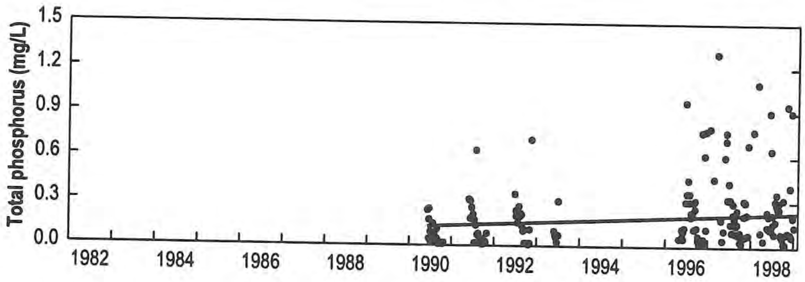

Figure 36: Time series of observed total phosphorus for Samson Brook North over the period 1990-98.

Table 16: Results of statistical analysis for trend tests in Samson Brook North. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	SK	0.09	3.742	<0.001	128	90	202	Emerging increase
TP	1990-98	obs	SK	0.013	4.445	<0.001	128	80	172	Emerging increase

3.4.5 Meredith Main Drain

Current Total Nitrogen Status: High

The overall median TN concentration in Meredith Main Drain was 2.4 mg/L for the 1988-98 monitoring period. Annual median concentrations ranged from 1.95 mg/L (1991) to 4.75 mg/L (1988). Extremes in sampled TN concentrations varied from a minimum of 0.49 mg/L to a maximum of 18 mg/L. The observed data was seasonal, but upon flow adjusting the data was found to contain no evidence of seasonal patterns. The trend tests found evidence of increasing trends in both observed and flow-adjusted TN concentrations in Meredith. The observed data had an increasing trend of +0.10 mg/L/yr and the flow-adjusted TN had an increasing trend of +0.136 mg/L/yr in Meredith Main Drain over the 1990-98 monitoring period (Figure 37; Table 17). The trends are large and probably due to an increase in TN concentration variation in recent years of monitoring.

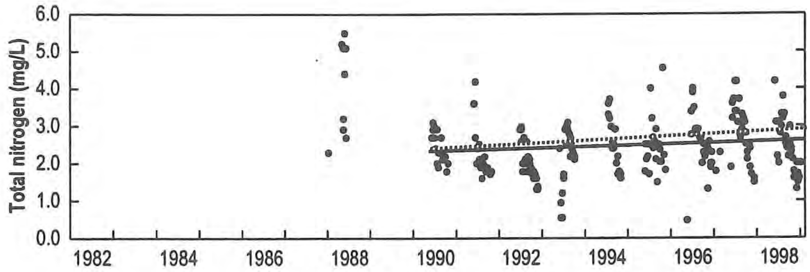

Figure 37: Time series of observed (black line) and flow-adjusted (dotted line) total nitrogen for Meredith Main Drain over the period 1988-98.

Current Total Phosphorus Status: Extreme

The overall median TP concentration in Meredith Main Drain was 0.59 mg/L/yr for the 1988-98 monitoring period. Annual median concentrations ranged from 0.53 mg/L (1997) to 1.1 mg/L (1990). Extremes in sampled TP concentrations varied from a minimum of 0.01 to a maximum of 1.5 mg/L. The data was not seasonal and hence the Mann Kendall trend test was used. There was no evidence of trend in the observed series, but when the data was adjusted for the effects of flow there was evidence of an emerging increasing trend (Figure 38; Table 17).

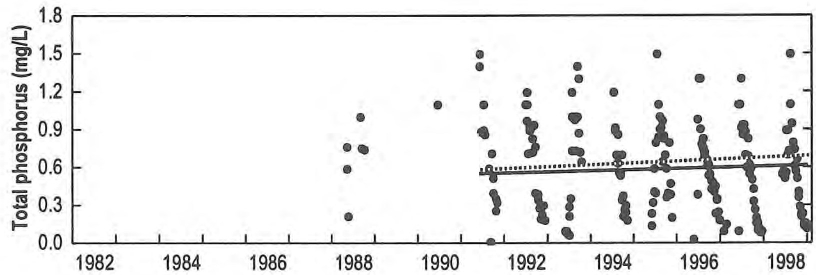

Figure 38: Time series of observed (black line) and flow-adjusted (dotted line) total phosphorus for Meredith Main Drain over the period 1988-98.

Table 17: Results of statistical analysis for trend tests in Meredith Main Drain. (Obs = observed data, FAC = flow-adjusted data, SK = Seasonal Kendall test, MK = Mann Kendall test, n = number of collected samples, n* = number of independent samples collected, n# = required number of samples to detect a trend).

Nutrient	Period	Series	Test	Slope	Z-stat	p-value	n	~n*	~n#	Trend Result
TN	1990-98	obs	SK	0.1	7.169	<0.001	177	79	56	Increasing trend
	1990-98	FAC	MK	0.136	8.734	<0.001	177	74	23	Increasing trend
TP	1991-98	obs	MK	0.002	0.095	0.924	152	73	59562	No trend
	1991-98	FAC	MK	0.036	3.814	<0.001	152	61	89	Emerging increase

4. Discussion

Detecting trends in nutrient concentration and, where appropriate, flow-adjusted concentrations in waterways can provide valuable information to environmental managers about changes in water quality and potential impacts to receiving waterbodies. Trends in water quality may be statistically significant, but whether the trend has environmental significance is another issue and will warrant further investigation.

4.1 Interpreting trends in water quality

Practical significance has been defined in terms of trends that "indicate internal catchment change" (Robson and Neal, 1996), or as "changes that match our understanding of the system and the way it responds to external inputs" (Loftis, 1996). However, the statistical definition of what constitutes a trend of practical (or for that matter environmental) significance is much more difficult. Statistical trends in nutrient concentration may be meaningless if, from an environmental perspective, they are too small to produce a shift in the ecological condition of a waterbody. Clearly, to influence biological productivity a trend in nutrient concentration must indicate a substantial change in the total loading of the system with nutrients. A large change in the total loading of a receiving waterbody may result from the sum of multiple inputs over a wide area. A trend in nutrients from a single input, even a small one, may also be environmentally important if it contributes directly to a hyrologically closed or a fragile ecosystem. In this context, waterways that are enriched but do not contain a trend may be as environmentally important as those that do.

The following provides an example of the interpretation of trends in nutrient concentration for various types of ecological systems. A decreasing trend in the nutrient concentrations in the upper Serpentine River site would have far reaching implications on the ecology of estuarine reaches of the river and the Peel Inlet. The Serpentine River is one the three major tributaries feeding the Peel-Harvey estuaries, discharging about 12% of the total volume of surface water input to the estuaries. If trends in nutrient concentrations were found for the Serpentine River the phytoplankton and macroalgae populations of the river and estuary are likely to be impacted; although the extent of the impact will also depend on other factors (such as sediment nutrient cycling, light availability, movement of salt wedge, etc.). A decrease in nutrient input would be environmentally beneficial, given that the lower Serpentine River experiences regular and prolonged summer and autumn blooms of *Nodularia* and dinoflagellates and the Peel Inlet experiences excess macroalgae growth (WRC, 1998).

In contrast to the previous example, a decreasing trend in nutrient concentrations of the same magnitude in Mealup Main Drain would not be expected to significantly influence the ecology of Harvey Estuary. The drain currently has an enriched nutrient status but is considered to be a relatively minor delivery source of nutrients to the estuaries (contributes less than one percent to the annual volume delivered to the estuaries). A large tidal exchange is also present in estuary, due to the Dawesville Channel, which would rapidly dilute nutrient concentrations discharged from the drain. The combination of these factors means that the ecological impacts on the estuary due to changes in Mealup Main Drain would be minimal. However, when the overall management objective is to lower net nutrient export then effective catchment management (even at the minor scale) will play an important role in achieving that outcome.

4.2 Trends in nutrients for monitored sites

Many monitored tributary inflows of the Peel-Harvey estuarine system showed evidence of increasing changes in nutrient concentration over their respective monitoring periods. It is unknown whether this is the result of changes in the monitoring program, land use, hydrology or climate and further research is necessary to determine the cause of the trends. The uncertainty in interpreting and explaining trends in water quality only highlights the need for a detailed information system that readily identifies both temporal and spatial changes in catchment condition.

Many of the increasing trends detected in the tributary inflows represent a gradual change in nutrient concentrations which is characteristic of diffuse source (i.e. groundwater) contributions. Although various forms of catchment management initiatives have been implemented in the past, the primary sink of nutrients in groundwater has remained relatively untouched. The transport of nutrients from catchment to groundwater and then to surface drainage is a relatively slow process (especially for phosphorus) and it is therefore likely that diffuse sources will persist for some time.

With this in mind, the focus of catchment management should be directed at managing both the land (with a long-term view of reducing both point and diffuse sources) and the waterway (with a short-term view to improving current water quality). While reducing point source contributions is achievable and will produce (almost) instantaneous improvements in water quality for some impacted waterways, diffuse sources are a much larger and more difficult problem to manage. Diffuse sources of nutrients are the major contributor to the Peel-Harvey estuarine system and therefore a reduction in loading to the estuarine system will not be apparent until groundwater sinks of nutrients are diminished.

4.2.1 Serpentine region

Only one of the four monitored sites in the Serpentine region had trends in nutrient concentrations over the monitoring period that were statistically and environmentally significant (Figures 39 and 40).

Nambeelup Brook is of interest to managers given that a obvious shift in water quality occurred over the 1990-98 monitoring period. Total nitrogen concentrations increased at a rate of +0.133 mg/L/yr and total phosphorus concentrations increased at a rate of +0.042 mg/L/yr. The current nutrient status indicates that the brook is nutrient enriched, especially with phosphorus. The land use in the catchment consists primarily of stock grazing and pasture development, although poultry farms, dairies, plantations and horticulture are also present. Sandy soils and duplexes (sands over clays) are common soil types in the catchment, so the leaching of nutrients to groundwater is likely to occur in some areas. The increasing nutrient supply to the brook is possibly derived from groundwater or a permanent point source. Irrespective of the source, nutrient concentrations in the brook are much higher compared to other waterways in the Serpentine region (with the exception of Gull Road Drain). This suggests that inappropriate wastewater discharge practices are occurring in the catchment and will warrant further investigation.

The increasing trends in nutrient concentration for Nambeelup Brook are of concern given it discharges directly to the lower reaches of the Serpentine River which experiences frequent summer blooms of dinoflagellates and toxic, blue-green algae (mainly *Nodularia* sp., but also *Anabaenopsis, Merismopedia, Oscillatoria, Anabaena* and *Microcystis* sp.). Blooms of the Haptophyte *Prymnesium*, which can be lethal to fish, have also occurred over recent years (autumns of 1997 and 1999) suggesting a possible change in phytoplankton species diversity. It is possible that increasing nutrient export from Nambeelup Brook may be a contributory factor to this shift, given it contributes about 6% of volume to the lower Serpentine River. Further deterioration in nutrient water quality for Nambeelup Brook is unacceptable and has the potential to produce further ecological impacts for the estuarine reaches of the Serpentine River and the Peel Inlet.

The only other evidence of a trend for monitored waterways in the Serpentine region was in flow-adjusted total phosphorus for Peel Main Drain over the 1990-93 period. The decreasing trend was large (-0.081mg/L/yr) and must be interpreted with caution as the rate of change may have been exaggerated due to the short period of analysis. It is unlikely the decreasing trend is environmentally significant unless total phosphorus concentrations continued to decline in the drain after 1993. Further monitoring is required to assess the current condition of the drain. Peel Main Drain drains a region undergoing rapid development and has numerous intensive land uses (piggeries, poultry farms, horticulture, stock holding yards, industry, etc), all which have the potential to affect nutrient export from the catchment. It has been recently estimated that about a third of the phosphorus and a quarter of the nitrogen in Peel Main Drain has been derived from effluent from a single sheep feedlot (Chambers and Hale, 1999). The drain contributes about 8% of the volume to the middle Serpentine River and will therefore have some impact on downstream ecology.

While there was no evidence of trend in nutrient concentrations for Gull Road Drain, in-stream nutrient concentrations have been consistently (and alarmingly) elevated for well over a decade. The drain is considered to be one of the most nutrient enriched waterways in Western Australia. A local piggery in the region is known to contribute faecal waste (i.e. nutrients) to the drain and the Serpentine River (Leeming, 1996). The drain is a relatively minor input to the lower Serpentine River, however it discharges excessive amounts of nutrients to an already fragile ecosystem. A revision of licence conditions and/or best management practices (BMPs) for intensive agriculture practices in the Serpentine region is recommended to reduce point source nutrient contributions to the Serpentine River.

Nutrient concentrations in the (upper) Serpentine River have not changed over the monitoring period. The current nutrient status in the Serpentine River indicates mild enrichment with phosphorus. For a major tributary inflow to the Peel-Harvey estuarine system (approximately 12% of total annual inflow) this warrants concern and may (in part) explain why the lower Serpentine River experiences excessive phytoplankton activity. The main source of phosphorus to the river is diffuse in nature, derived from fertiliser leached from agricultural properties in the catchment and transported via groundwater. Many intensive land use practices also exist on the coastal plain portion of the Serpentine River catchment which have the potential to contribute large amounts of nutrients via point sources.

Nutrient concentrations in Dirk Brook indicate mild enrichment but have shown no appreciable change over the 1990-98 monitoring period. Sources of nutrients are likely to be derived from both point and diffuse sources in the catchment.

4.2.2 Murray region

Of the two monitored sites in the Murray region, the site on South Dandalup River had trends in nutrient concentrations that were statistically and environmentally important (Figures 39 and 40).

South Dandalup River is of interest to managers given that it currently has a low nutrient status and had increasing changes in nutrient concentration over the 1990-98 monitoring period. Nutrient concentrations in the South Dandalup River are currently low, possibly due to the uptake of nutrients by remnant vegetation and the high phosphorus binding capacity of the laterites and clays of the Darling Scarp. Pasture development and stock grazing are the primary land use activities on the coastal plain, although dairies and horticulture are also present. Most of the upper catchment on the plateau remains forested, although some deforestation has occurred over the past decade. The river contributes about 5% of volume to the lower Murray River and about 3% to the Peel-Harvey estuarine system.

Analysis of the water quality data in South Dandalup River suggests that a new source of nutrients has been discharging to the river. An increasing trend of +0.072 mg/L/yr was detected in total nitrogen and an emerging increasing trend was detected in total phosphorus. The increasing trend in total nitrogen appears to be linked to an increase in nutrient concentrations collected during winter flows. Increased levels of nitrogen in sub-surface flows from duplex soils (particularly when groundwater levels are elevated) are the primary transport mechanisms. The emerging increasing trend in phosphorus requires more sampling to statistically confirm as a trend. An isolated pocket of land clearing on the Darling Scarp may be responsible for the apparent increase in nutrient concentrations in South Dandalup River, but further research is required to substantiate this.

The Murray River contributes the single greatest volume of water (approximately 60% of total annual inflow) to the Peel-Harvey estuarine system and therefore represents the single largest influence to estuarine ecology. Although nutrient concentrations in the river have been consistently low over the monitoring period, phytoplankton activity and diversity appear to have recently changed (WRC, unpublished data). Summer and autumn diatom blooms are a common occurrence in the lower estuarine reaches of the Murray River, but the frequency of dinoflaggelate (e.g. *Alexandrium* sp.) and chlorophyte blooms appears to be increasing. The trend analysis indicated that nutrient water quality in the Murray River has not changed over the monitoring period; therefore the apparent shift in phytoplankton activity/diversity may reflect a change in the bioavailable nutrient fraction or micronutrients being delivered to the river. While the data series shows a reduction in the frequency of high nutrient concentrations collected after 1990, it may simply be reflecting a change in sampling regimes. When monitoring first commenced in 1983, grab samples were collected during high flows to meet the objectives of generating nutrient loading estimates. More recently (post-1990) grab samples have been collected at fixed-intervals to meet trend detection objectives. The change in sampling regimes in the Murray River, combined with periods of missing data, made the statistical analysis of trends difficult.

4.2.3 Drains to the estuaries

Only one of the drains discharging directly to the Peel-Harvey estuarine system showed evidence of trend (Figures 39 and 40).

Caris Drain was the only monitored site in the region where an increasing trend (+0.012 mg/L/yr) was detected in flow-adjusted total phosphorus over the 1990-98 monitoring period. The trend was not large and occurred in a drain that contributes less than 1% of the total annual volume delivered to the Peel-Harvey estuarine system. Pasture development and stock grazing are the primary land uses in the catchment. The catchment consists largely of sands over clays (i.e. duplex soils), so sub-surface and overland flows represent the dominant hydrologic pathways. The trend in Caris Drain is due to an increase in seasonal variation in recent years and may be attributed to a change in fertilising regimes or it may represent the breakthrough of a plume of phosphorus. The trend is not likely to be ecologically significant given its small magnitude and the small volume the drain discharges to Coolup Main Drain and the Peel Inlet.

The only other evidence of change in this region was for South Coolup Main Drain. Emerging increasing trends were found for both total nitrogen and total phosphorus, but require more sampling to statistically confirm as trends. Further analysis will also be required to determine if the nutrient data series in the drain are simply reflecting long-term variation in groundwater levels.

The other agricultural drains in this region were generally nutrient enriched, but all represent relatively minor inflows to the estuarine system. Duplex (sands over clay) soils are the predominant soil type in the region and are conducive for the rapid lateral transport of nutrients in saturated soil conditions. Although the drains represent minor flows to the estuaries, the high nutrient concentrations in baseflows are indicative of nutrient-enriched groundwater in this region. It is therefore likely that groundwater discharge contributes a large diffuse source of nutrients to the estuaries and, given the process occurs over a regional scale, will be ecologically significant.

4.2.4 Harvey region

Only one site in the Harvey region showed evidence of trends in nutrient concentration that was of statistical and ecological importance (Figures 39 and 40).

Meredith Main Drain is of interest to managers given it is nutrient-enriched and shows evidence of further deterioration. An increasing trend of +0.136 mg/L/yr was detected in flow-adjusted total nitrogen and an emerging increasing trend in total phosphorus was also apparent over the 1990-98 monitoring period. The drain contributes about 3% towards the total volume discharged by the Harvey River and (given its nutrient enriched state) is expected to impact riverine and estuarine ecology. Stock grazing and the development of pasture are the major land uses in the catchment and rely on regular applications of fertilisers. The Meredith catchment consists solely of nutrient-deficient sandy soils that are regularly inundated, so the diffuse leaching of nutrients from the sandy agricultural soils to groundwater is likely to be the primary transport mechanism.

Phosphorus export from agricultural soils in the Meredith catchment has been the focus for recent catchment management initiatives, including 'streamlining' (Heady and Guise, 1994) and the application of bauxite residue ('red mud') to prevent phosphorus leaching (Summers *et al.*, 1996; Summers and Pech, 1997; Rivers, 1998; Summers and Rivers, 1999). The application of fertilisers to the nutrient-deficient sandy soils has been occurring for many decades in the Meredith catchment which has produced a large groundwater sink of nutrients. This is apparent from the high nutrient concentrations in baseflow (i.e. groundwater discharge) conditions in the drain. While the application of bauxite residues have proven effective for the retention of applied phosphorus to surface soils, an improvement in nutrient water quality for Meredith Main Drain due to this activity is not likely to be apparent for many years to come. Improvements in nutrient water quality will not occur until current baseflow nutrient concentrations are lowered. In the interim, the best solution is to manage the nutrients currently being intercepted and discharged by the drain. Studies have shown that increasing riparian revegetation and restoring riverine condition (i.e. 'streamlining') will enhance nutrient retention and thus would be considered a viable management option for lowering baseflow nutrient concentrations (Heady and Guise, 1994; Gburek *et al.*, 2000). The management of nutrient export from the catchment with both short and long-term objectives in mind is the key to improving nutrient water quality in Meredith Main Drain.

Samson Brook North showed evidence of increasing emerging trends for both total nitrogen and total phosphorus; however further monitoring is required to statistically confirm them as trends. Mining operations situated in the upper catchment may be impacting water quality in the brook, although further investigations are required to confirm this.

Nutrient water quality in Mayfields Main Drain was surprisingly good compared to that in neighbouring waterways and showed no evidence of trend. Land use in the catchment is similar to that in adjacent catchments (i.e. dairies, pasture development and stock grazing), so applied levels of nutrients would be comparable. The high clay content of the soils, effective catchment management or improved farming practices may explain the low nutrient concentrations in the drain.

The Harvey River provides the second largest volume of water to the Peel-Harvey estuarine system (approximately 20% of total annual inflow) and is therefore expected to have a significant effect on estuarine ecology. Nutrient concentrations are somewhat elevated for a major tributary inflow which may be attributed (in part) to intensive land use practices in the catchment. Unfortunately, the estuarine reaches of the Harvey River are not currently monitored for phytoplankton, so an assessment of ecological change was not possible. Nutrient concentrations in the Harvey River are similar compared to the Serpentine River

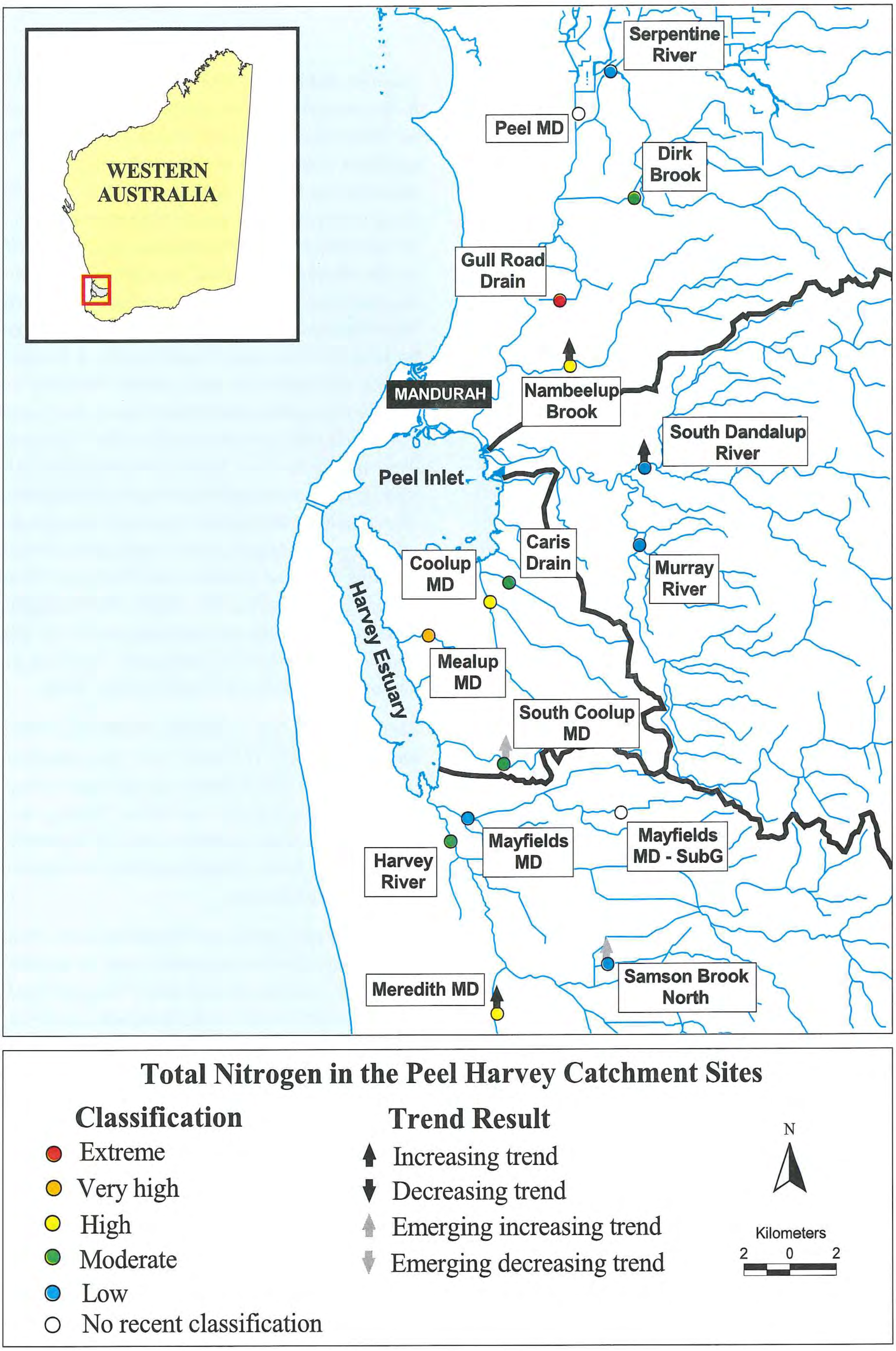

Figure 39: The status and trend of total nitrogen for the Peel-Harvey catchment sites. Total nitrogen status has been determined using the classification scheme for the most recent classification period (1996-98). The trend arrow represents the results of the trend test for total nitrogen in the most recent analysis period. Where trend tests were performed on both observed and flow-adjusted data, only the result for the latter was displayed.

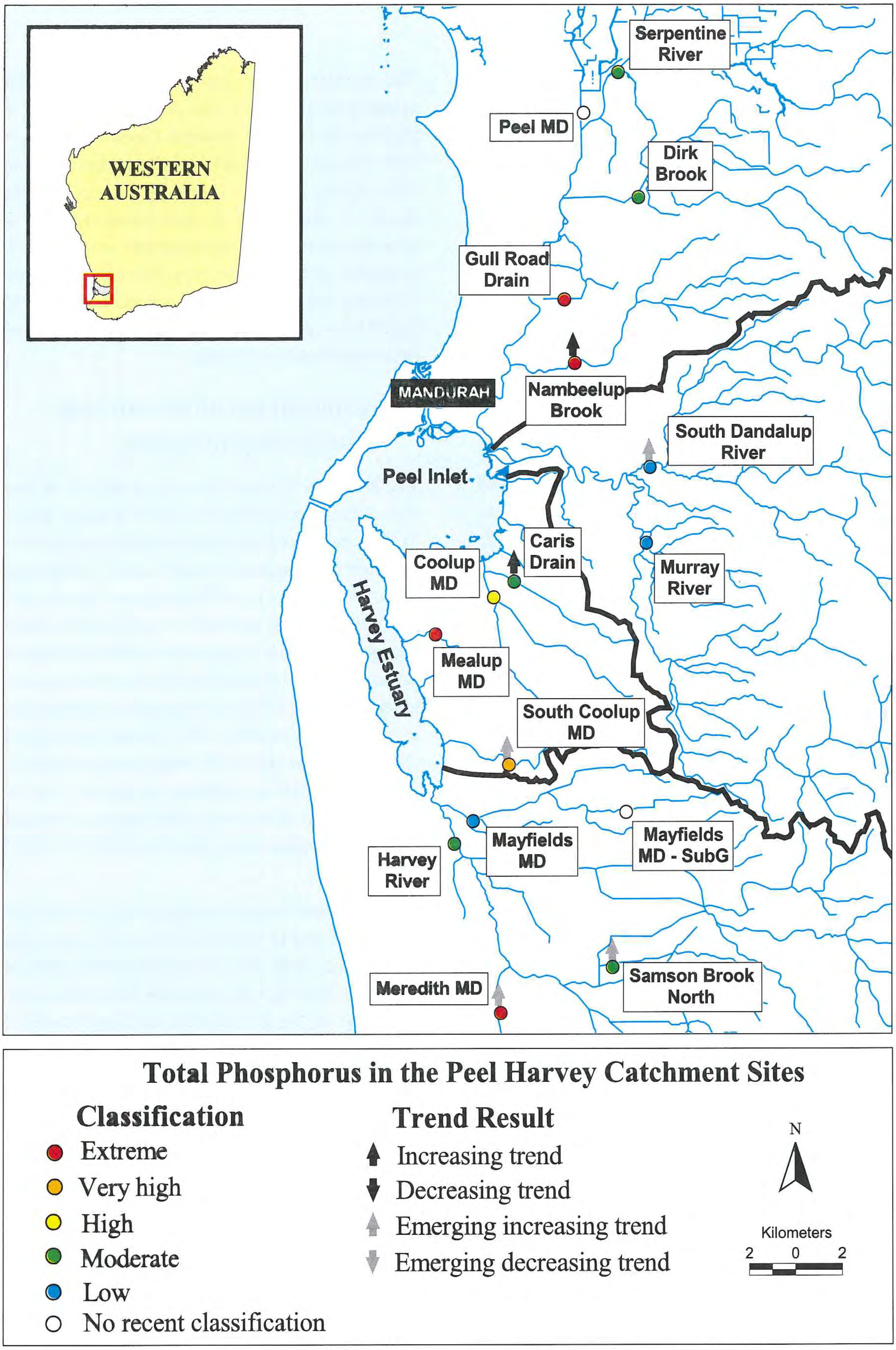

Figure 40: The status and trend of total phosphorus for the Peel-Harvey catchment sites. Total phosphorus status has been determined using the classification scheme for the most recent classification period (1996-98). The trend arrow represents the results of the trend test for total phosphorus in the most recent analysis period. Where trend tests were performed on both observed and flow-adjusted data, only the result for the latter was displayed.

suggesting that nuisance phytoplankton blooms (such as *Nodularia* sp.) may be a common occurrence. The trend tests showed no evidence of change in nutrient water quality, however the availability of continuous flow and nutrient data and the use of consistent sampling regimes may have provided a better indication of change (if any did occur) over the monitoring period.

4.3 Design considerations of the monitoring program

Had the Peel-Harvey catchment monitoring program been designed with a statistical approach to detect trends in concentration at its inception, the ratio of trend magnitude to variance, error risks and the trend model would be used as the primary design criteria (Loftis, 1996). However, the program was originally designed to supply estimates of annual nutrient mass loading of the estuaries (Wittenoom *et al.*, 1998). The selection of a weekly sampling frequency was not made on any statistical reasoning or definition of an appropriate trend model. This is why careful attention was given in this analysis to *a posteriori* assessment of sample size and error risk definition. Previously, it was not known how big a trend would be before it would be detected by the monitoring program.

In order to define the sensitivity of the monitoring program to detect change, it is of interest to know the range of trend magnitudes that were detected by the analysis procedures used and the period over which they occurred. On face value ($Z > 1.96$; $p < 0.05$), the statistical tests (Mann-Kendall and Seasonal Kendall) detected a total of 32 statistically significant trends for all monitored sites for both observed and flow-adjusted data series in this report. The relative size of the statistically significant trends ranged between -0.001 mg/L/yr (which is essentially meaningless) and +0.50 mg/L/yr.

However, with the inclusion of an a posteriori assessment of sample size, definition of error risks and removal of correlation in the data series ($Z = 1.96$, $p < 0.05$ and $n\# \approx n*$), it reduced the number of statistically significant trends from 32 to 7. The insignificant trends that were eliminated were generally small in magnitude, had a high variance about the trend line and/or would have required high sampling frequencies to detect trends in the periods tested. The largest, statistically significant trends eliminated by the a posteriori assessments had slopes of +0.50 mg/L/yr in observed nitrogen (Gull Road Drain, 1990-98) and +0.05 mg/L/yr in observed phosphorus (Mayfields Main Drain—SubG, 1990-93).

The smallest trends detected following a posteriori assessment of sample size requirements were +0.072 mg/L/yr in observed nitrogen (South Dandalup River; 1990-98) and +0.012 mg/L/yr in flow-adjusted phosphorus (Caris Drain; 1991-98). Generally, the number of samples needed to detect most of these trends (n#) was far less than the number of independent samples currently available (n*). Preliminary calculations show that collecting one sample every two weeks (instead of weekly) would have probably have been sufficient and resulted in the detection of most trends.

4.4 Limitations of the current monitoring program

The detection of trends in water quality is an important and essential component of environmental assessment. Trends can be used to provide management with estimates of rates of progress toward water quality goals or objectives. However, information on trends should be interpreted against catchment management activity and changes in land use. Irregular, static descriptions of land-use in the monitored catchments are of little use except to identify potential sources and explain spatial differences in average water quality. They can not explain temporal changes in water quality. It is important to monitor changes in land-use and management initiatives (i.e. reduced fertiliser application, revegetation programs, streamlining) and then to compare these activities with trends in nutrient water quality.

At the time this analysis was carried out, it was not possible to correlate any of the trends in nutrient water quality to changes in land use or implemented management strategies. This lack of assessable information decreases the value of the information being generated by the monitoring program and by the detection of trends. Developing monitoring programs that integrate the implementation of management strategies and changes in land use with desired information objectives should be a priority for designers of environmental monitoring programs.

Lack of available flow data for many monitored sites also limits the value of the information generated from the trend analysis. Flow-adjusted trends provide managers with an enhanced perception of change in tributary water quality by removing the influence of flow (i.e. a form of natural variation) from the data. Therefore, when the information goals of a monitoring program are to detect changes in the water quality, it is imperative that the monitoring of water quality for tributary inflows be performed synonymously with the monitoring of flow.

5. Recommendations

The challenge in the future is to reverse the trend of degradation and to improve the condition of the tributary inflows to the Peel-Harvey estuarine system. To assist with policy and resource allocation, managers need to understand the current condition of rivers and how management activity and land use may affect water quality, ecosystem condition and bio-diversity. In this context, the identification of current condition and trends in water quality are especially important. The following recommendations are linked to the findings contained in this report.

5.1 Sources of nutrients

Many tributary inflows to the Peel-Harvey estuarine system showed evidence of nutrient enrichment, particularly those situated on duplex or sandy soils that are seasonally inundated. Some also showed evidence of increasing trends in nutrient water quality, although nutrient water quality in the major inflows appeared relatively stable over the monitoring period. Nutrient export from the Peel-Harvey catchment can be attributed to both point and diffuse source problems.

Point Sources

- **Action: Identify and control nutrient point sources discharging directly or indirectly to surface drainage systems.**
- **Action: Promote the development and use of Best Management Practices (BMPs) in pollution prevention for intensive livestock practices (i.e. piggeries, poultry farms, dairies, stock holding yards, etc) and industry.**

Diffuse Sources

- **Action: Continued education of the general community about the effects of over-fertilisation, over-watering and inappropriate wastewater discharge practices.**
- **Action: Upgrade sewerage systems in older residential areas, especially those in low-lying areas or adjacent to surface drainage.**
- **Action: Ensure Water-Sensitive Design principles are incorporated in catchment management guidelines for all new land development proposals, infill development and for any new planning initiatives.**
- **Action: Limit or control livestock access (i.e. fencing) to waterways and agricultural drains to reduce the direct input of faecal waste material and to prevent further degradation of riparian zones. Continue to promote and enhance 'streamlining' activities.**
- **Action: Encourage farmers to routinely test the nutrient availability in soils prior to fertiliser application and apply required nutrients at more strategic times of the year.**
- **Action: The use of slow-release fertilisers is highly recommended for agricultural properties with sandy soils and/or a seasonally high watertable.**
- **Action: Advise against further clearing of remnant vegetation on the Swan Coastal Plain.**

5.2 The monitoring program

The information objectives of the nutrient monitoring program in the Peel-Harvey catchment needs to be reviewed and defined in terms of the statistical detection of trends.

- **Action: Preliminary trend results indicate that the sampling frequency can be reduced from weekly to fortnightly with little or no information loss for many monitored sites.**
- **Action: Continue to monitor nutrients (both totals and fractions) at existing sites in the Peel-Harvey catchment. Consider the introduction of routine monitoring at other major waterways and drains that discharge to the major inflows, for example Peel Main Drain.**

The value of the information being generated from the nutrient monitoring program is compromised without adequate complementary information about catchment condition and any changes occurring therein.

- **Action: Monitor and record spatial changes in land use, farming practices, industrial/commercial practices and management initiatives in the Peel-Harvey catchment in an attempt to explain trends in nutrient water quality in waterways.**

- **Action: Consider monitoring nutrient-enriched waterways on a sub-catchment scale to identify 'hot-spots' and to enable better allocation of management attention and resources.**

- **Action: Commence phytoplankton monitoring in the estuarine reaches of the Harvey River to determine if phytoplankton diversity or bloom occurrence is changing.**

- **Action: Continuously monitor flow for all monitored tributaries in the Peel-Harvey catchment monitoring program with an aim to providing management with an improved perception of trends in water quality. Upgrade current gauging stations to include precision of flow data.**

References

APHA: American Public Health Association (1992). *Standard methods 18th edition for the examination of water and wastewater.* American Public Health Association, American Water Works Association and Water Environment Federation.

Aulenbach, B.T., Hooper R.T. and Bricker E.P. (1996). 'Trends in the chemistry of precipitation and surface water in a national network of small watersheds'. *Hydrological Processes,* 10 (2): 151-181.

Bayley, G.V. and Hamersley (1946). 'The effective number of independent observations in an auto-correlated time series'. Supplement to the *Journal of the Royal Statistical Society,* 8:184-197.

Chambers, J.M. and Hale, J.A. (1999). *Improving in-stream assimilation of nutrients in the Peel Main Drain.* Murdoch University, Western Australia. Miscellaneous Report, May 1999.

Close, M.E. (1989). 'Effect of serial correlation on groundwater water quality sampling frequency'. *Water Resources Bulletin* 25: 507-515.

Davidson, W.A. (1995). *Hydrogeology and groundwater resources of the Perth region, Western Australia*: Western Australia Geological Survey, Bulletin 142.

Deeley D.M., Paling E.I. and Humphries R. (1999). 'Why south western Australian estuaries are highly susceptible to nutrient enrichment'. In *Proceedings of the international conference on diffuse pollution,* CSIRO Land and Water, Perth, Western Australia: 176-190.

Esterby, S. R. (1996). 'Review of methods for the detection and estimation of trends with emphasis on water quality applications'. *Hydrological Processes,* 10 (2): 127-149.

Gburek, W.J., Sharpley A.N., Heathwaite, L. and Folmar, J.G. (2000) 'Phosphorus management at the watershed scale: a modification of the phosphorus index'. *Journal of Environmental Quality,* 29, 130-144.

Gerritse, R.G., Barber, C., and Adency, J.A. (1990). *The impact of residential urban areas on groundwater quality; Swan Coastal Plain of Western Australia.* Water Resources Series No. 3, CSIRO.

Gerritse, R.G. and Adency, J.A. (1992). *Nutrient exports from various land uses on the Darling Plateau in Western Australia: effects on stream water quality.* Report No. 92/41, CSIRO, Division of Water Resources, Australia.

Gilbert, R.O. (1987). *Statistical methods for environmental pollution monitoring.* Van Nostrand Reinhold, New York. 250 pp.

Harned, D.A., Daniel, C.C. III, and Crawford, J.J. (1981). 'Methods of discharge compensation as an aid to the evaluation of water quality trends', *Water Resources Research,* 17: 1389-1400.

Heady, G. and Guise, N. (1994). *Streamlining: An environmentally sustainable drainage network for the Swan Coastal Plain (Peel-Harvey catchment).* Department of Agriculture, Western Australia, Bulletin 4279.

Heathwaite, A.L. and Johnes, P.J. (1996). 'Contribution of nitrogen species and phosphorus fractions to stream water quality in agricultural catchments'. *Hydrological Processes,* 10: 971-983.

Helshel, D.R. and Hirsch, R.M. (1992). *Statistical methods in water resources.* Elsevier, Amsterdam. 522 pp.

Hipel, K.W. and McLeod, A.I. (1994). *Time series modelling of environmental and water resources systems.* Elsevier, Amsterdam.

Hodgkin, E.P. and Hamilton, B.H. (1993). Fertilizers and eutrophication in south-western Australia: Setting the scene. *Fertilizer Research,* 36: 95-103.

Kinhill Engineers Pty Ltd (1988). *Peel Inlet and Harvey estuary management strategy: Environmental review and management program—Stage 2.* Department of Agriculture, Perth, Western Australia.

Lachance, M. (1992). 'Monitoring Lakes in Quebec'. Case study in: *Design of water quality monitoring systems.* R. Ward, J. Loftis and G. McBride. Van Nostrand Reinhold, New York.

Leeming, R. (1996). *Examination of faecal sterols in sediments of the Serpentine and Murray Rivers, Western Australia.* CSIRO Division of Oceanography. Report 96-PIMA1.

Lettenmaier, D.P., (1976). Detection of trends in water quality from records with independent observations. *Water Resources Research*, 12 (5):1037-1046.

Lettenmaier, D.P., Hooper, E.R., Wagoner, C., and Faris, K. (1991). 'Trends in stream quality in the continental United States, 1978-1987'. *Water Resources Research*, 27 (3): 327-339.

Loftis, J. (1996). *Trends in groundwater quality. Hydrological Processes*, 10 (2): 335-355.

Loftis, J.C., McBride, G.B. and Ellis, J.C. (1991). Considerations of scale in water quality monitoring and data analysis. *Water Resources Bulletin*, 27 (2): 255-264.

McBride, G.B., Loftis, J.C. and Adkins, N.C. (1993). 'What do significance tests really tell us about the environment?' *Environmental Management*, 17: 423-432.

McComb, A.J. and Lukatelich, R.J. (1986). 'Nutrients and plant biomass in Australian estuaries, with particular reference to south-western Australia'. In: *Limnology in Australia.* P. De Deckker and W.D. Williams (eds). Dordrecht.

Rast, W. and Thorton, J.A. (1996). 'Trends in eutrophication research and control'. *Hydrological Processes*, 10 (2): 295-313.

Reddy, K.R. and D'Angelo, E.M. (1994). 'Soil processes regulating water quality in wetlands'. *Global Wetlands: Old World and New*, Elsevier Science B.V., Florida, USA.

Rivers, M. (1998). *The use of bauxite residue as a soil amendment in the Peel-Harvey coastal plain catchment.* Agriculture Western Australia. Miscellaneous Publication 15/98.

Robson, A.J., and Neal, C. (1996). Water quality trends at an upland site in Wales. *Hydrological Processes*, 10 (2): 183-203.

Ruprecht, J.K. and George, P.R. (1993). Hydrology of the Peel-Harvey estuary catchment. *Fertilizer Research*, 36: 127-133.

Sanders, T.G., War, R.C., Loftis, J.C., Steele, A.D.D, Yevjevich, V. (1987). *Design of networks for monitoring water quality (2nd edition).* Water Resources Publications. Littleton, Colorado.

Slater, J.M. and Capone, D.G. (1987). 'Denitrification in aquifer soil and nearshore marine sediments influenced by groundwater nitrate'. *Applied Environmental Microbiology*, 53, 1292-1297.

Smith, R.L. and Duff, J.H. (1988). 'Denitrification in a sand and gravel aquifer'. *Applied Environmental Microbiology*, 54, 1071-1078

Stoddard, J.L., Scott Urquhart, N., Newell A.D. and Kugler D.(1996). The Temporally Integrated Monitoring of Ecosystems (TIME) project design 2. Detection of regional acidification trends. *Water Resources Research.* 32 (8): 2529-2538.

Summers, R.N., Smirk, D.D. and Karafilis, D. (1996). 'Phosphorus reduction and leachates from sandy soil ammended with bauxite residue (red mud)'. *Australian Journal of Soil Research*, 34, 555-67.

Summers, R.N. and Pech, J.D. (1997). 'Nutrient and metal content of water, sediment and soils amended with bauxite residue in the catchment of the Peel Inlet and Harvey Estuary, Western Australia'. *Agriculture, Ecosystems and Environment*, 64, 279-232.

Summers R. and Rivers M. (1999). Phosphorus in runoff from the coastal catchment of the Peel Inlet and Harvey Estuary and innovative solutions for control. In *Proceedings of the international conference on diffuse pollution.* CSIRO Land and Water; Perth, Western Australia.

Valiela, I., Collins, G., Kremer, J., Lajtha, K., Geist, M., Seely, B., Brawley, J., Sham, C.H.. (1997). Nitrogen loading from coastal watersheds to receiving estuaries: new method and application, *Ecological Applications*, 7, 358-380.

Ward, R., Loftis, J. and McBride, G. (1990). *Design of Water Quality Monitoring Systems.* Van Nostrand Reinhold, New York.

Water and Rivers Commission (1998). *Dawesville Channel Monitoring Program: Technical Review Report.* Water and Rivers Commission Report, WRT 28, Perth, Western Australia.

Wittenoom, P., Donohue, R. and Bowyer, L. (1998). *A critique of the Peel/Harvey catchment monitoring and compliance testing programme.* Draft report, Water and Rivers Commission.

Zhou, Y. (1996). 'Sampling frequency for monitoring the actual state of groundwater systems'. *J. Hydrology*, 180: 301-318.